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NASA Technical Memorandum 85632

# NASA Oceanic Processes Program

## Annual Report - Fiscal Year 1982

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25th Anniversary
1958-1983

NASA

NASA Technical Memorandum 85632

# NASA Oceanic Processes Program

## Annual Report - Fiscal Year 1982

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*Washington, D.C.*

National Aeronautics
and Space Administration

**Scientific and Technical
Information Branch**

1983

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# PREFACE

This, the Third Annual Report for NASA's Oceanic Processes Program, provides an overview of our recent accomplishments, present activities, and future plans. Although the report was prepared for Fiscal Year 1982 (October 1, 1981 to September 30, 1982), the period covered by the Introduction extends into March 1983. Sections following the Introduction provide summaries of current flight projects and definition studies, brief descriptions of individual research activities, and a bibliography of refereed journal articles appearing within the past two years. We hope you find the report useful, and we would appreciate hearing from you in the event you have any questions or comments.

We would like to express our appreciation to all those individuals who have contributed material to our report.

Wayne E. Esaias
Watson W. Gregg
William C. Patzert
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William F. Townsend
W. Stanley Wilson

Oceanic Processes Program
Code EE-8
Washington, DC 20546
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## SECTION I - INTRODUCTION

The overall goals of the Oceanic Processes Program are (1) to develop spaceborne techniques and to evaluate their utility for observing the oceans, (2) to apply these techniques to advance our understanding of the fundamental behavior of the oceans, and (3) to assist users with the implementation of operational systems. We are working closely with the operational oceanographic community because many of the specific research questions being addressed by our program--when answered--will help provide an improved capability for the utilization of spaceborne techniques for operational purposes.

The program is organized into five components; they and their respective program managers are: (1) Ocean Circulation - Dr. William C. Patzert; (2) Air-Sea Interaction - Dr. Patzert (Acting); (3) Ocean Productivity - Dr. Wayne E. Esaias; (4) Polar Oceans - Dr. Robert H. Thomas; and (5) Oceanic Flight Projects - Mr. William F. Townsend. Mr. Watson W. Gregg provides staff support to the group and its leader, Dr. W. Stanley Wilson. During the past year, Dr. Patzert has replaced Dr. Lawrence F. McGoldrick, who has taken a position with the Applied Physics Laboratory of the Johns Hopkins University; Dr. Esaias has replaced Dr. Kendall L. Carder, who has returned to his permanent position at the University of South Florida; Dr. Thomas and Mr. Gregg have assumed previously unfilled positions.

Funds available to the Oceanic Processes Program in Fiscal Year 1982 amounted to approximately $17 million (M); this supported all of the project and study activities noted in Section II (with the exception of the separately funded Nimbus-7 and TIROS-N projects), as well as 95 specific research activities. The distribution of funding according to institutions was roughly as follows:

| | |
|---|---|
| Jet Propulsion Laboratory | $ 8.6 M |
| Goddard Space Flight Center/ Wallops Flight Facility | 3.4 |
| Langley Research Center | 0.9 |
| Academic Institutions | 3.2 |
| Miscellaneous (other government & commercial) | 0.7 |

On a project/study basis, the Ocean Topography Experiment (TOPEX) received about $5.3 M. For the 95 specific research tasks, approximately $3.2 M went to 32 investigators at academic institutions, $7.3 M went to 50 investigators at NASA Centers, and $0.7 M went to 13 investigators at other government and commercial institutions. In addition, the Information Systems Office at NASA

Headquarters provided approximately $1.4 M for the Pilot Ocean Data System at JPL.

Funds available in Fiscal Year 1983 will continue at the $17 M level, while an increase to $18.2 M is anticipated for Fiscal Year 1984. For those respective years, TOPEX is anticipated to receive something in excess of $4 M.

Notable highlights for the overall Oceanic Processes Program during this past year relate to Seasat and Science Working Groups. Although Seasat as a project has been completed for over a year, its final report, "Seasat Data Utilization Project Report," was published last summer; it contains an extensive bibliography ranging from workshop documents to refereed journal articles. Scientific analyses of Seasat data have been underway and will continue for some time, the most recent publication being a second dedicated issue of the Journal of Geophysical Research, March 1983, Volume 88 (C3), pp. 1529-1952.

Various Science Working Group (SWG) activities have been underway during the past few years and are outlined in Table 1. The focus has been on the definition of science questions addressable by particular ocean satellite sensors and then on the corresponding performance specifications for those same sensors. A summary of the more recent SWG activities is given in Section II; written reports for each are available from NASA Headquarters.

We have implemented the Pilot Ocean Data System (PODS) at JPL in conjunction with Anthony Villasenor of the NASA HQ Information Systems Office. This system provides a centralized data base facility which will assist users in acquiring and managing the voluminous data sets associated with satellite sensors. In Fiscal Year 1982 we archived data from the Seasat altimeter, scatterometer, and Scanning Multichannel Microwave Radiometer (SMMR) on the system, and installed interactive terminals at six major oceanographic institutions. In Fiscal Year 1983 we plan to acquire new data sets from the Coastal Zone Color Scanner (CZCS) on Nimbus-7 and the Advanced Very High Resolution Radiometer (AVHRR) on NOAA's TIROS, from which a correlated time series will be produced. A Sea Surface Temperature Workshop will utilize PODS facilities, and eventually data from the Special Sensor Microwave Imager (SSMI) on the Air Force's Defense Meteorological Satellite Program (DMSP) mission will be archived.

## Ocean Circulation and Air-Sea Interaction Programs

The goal of the Ocean Circulation and Air-Sea Interaction programs is to determine the general circulation, heat content and horizontal heat flux of the oceans, and to develop an understanding of the ocean's role in climate variability. Specific objectives are to determine the geostrophic and wind-driven components of ocean circulation using spaceborne observations. Data from the planned TOPEX altimeter and the Navy's Remote Ocean Sensing System (NROSS) scatterometer form the basis of these programs. In order to provide a sound scientific framework, we have emphasized both theoretical studies and in situ ocean observing techniques to complement satellite data. Numerical modelling studies are aimed at the eventual operational use of these satellite products.

Significant accomplishments during Fiscal Year 1982 include: further analysis of Seasat data sets to produce the first global maps of mean wind speed, wave height, mesoscale ocean circulation variability; extraction of ocean tidal data for correction of topography and orbit determinations; and determination of the local bathymetry near the Musicians Seamounts from altimetry data. A project to de-alias scatterometer winds on 1° squares for 2 weeks of September 1978 is nearing completion.

In cooperation with the National Oceanic and Atmospheric Administration (NOAA) and the Office of Naval Research (ONR), we produced an engineering and scientific program to advance the technology and understanding of measurement systems on drifting buoys. Known as DRIFTERS, the program will support TOPEX and the World Ocean Circulation Experiment (WOCE)--an international experiment planned for the late 1980's. Development is now underway on the following in situ systems: a satellite-linked relay system to provide long-term measurements of various physical properties of the interior ocean, a cost-effective and well-calibrated Langrangian drifter, and acoustic doppler current profilers. A bottom-mounted profiler was successfully tested in the Coastal Ocean Dynamics Experiment (CODE), and shipboard versions are being constructed.

In the area of modelling, advances include: incorporation of sea-surface height data into dynamic models of upper ocean heat content, construction of baroclinic circulation models which make optimal use of remotely sensed data, development of a Gulf of Mexico model driven by altimeter topography data, and development of a local tide model for determining lunar semi-diurnal tides on Lake Superior. Theoretical studies for determining ocean circulation at depth from surface data using advanced modelling techniques were developed.

An important component of our program is to advance our understanding of physical processes in the air-sea boundary layers. Parameters include ocean surface waves, surface wind stress, and the ocean surface current response to this stress. In wave research, investigators developed non-linear wave spectra for wind-generated waves, a method for accurately determining ocean wave spectra from Seasat Synthetic Aperture Radar (SAR) images, aircraft radar for measuring the ocean wave directional height spectrum, and progress was made on obtaining wave height and surface current from Seasat SAR digital data. The SAR calibration study and Seasat SAR engineering assessment were completed, and methods for parameterizing vertical fluxes of heat, moisture, and momentum of the air-sea interface were identified.

Modelling efforts will continue to hold high priority in the Ocean Circulation program in Fiscal Year 1983. Major thrusts include the development of an equatorial circulation model, extending the tide models to the North Atlantic and Indian Oceans, and increased support for a NASA high speed vector processor to be used for large-scale coupled ocean-atmosphere modelling. The completion of our forecast impact studies will provide a preview of the future utility of satellite data. The new in situ development programs we have sponsored for the past few years are nearing the testing phase. In Fiscal Year 1983, the next generation prototype drifting buoy will be built and field tested, a network of island tide and data collection stations--already underway--will be developed and installed in the Pacific, and further refinements and field tests will be conducted for the acoustic doppler current profilers, both bottom-mounted and self-contained.

Thrusts in Air-Sea Interaction will be to continue modelling and data analysis programs in order to fully understand the oceanic wave environment and its application to scatterometer and other radar data. Development will continue on determining the ultimate accuracy of surface wind measurements for the Seasat scatterometer data. Basic ocean wave research will include: a comparison of surface contour radar and short pulse radar techniques for ocean wave spectra measurements for a fetch-limited sea, development of analytic model and laboratory studies to establish the contribution of breaking waves to upper ocean dynamics, and development of an analytic non-Gaussian statistical model for the wind-wave field. A conceptual study of the feasibility for determining global ocean surface currents from geostationary satellites will continue. Looking to the future, projects include the definition of a shuttle radar ocean wave spectrometer and advanced SAR techniques for high resolution ocean wave surface measurements.

## Ocean Productivity Program

The long range goal of the Ocean Productivity program is to determine the primary productivity of the oceans, its variability, how it is influenced by ocean circulation and the atmosphere, and how it in turn influences the marine food chain, the rate of global $CO_2$ uptake, and climate. The specific objectives are to assess and improve the accuracy of our capabilities to determine phytoplankton abundance and primary productivity based on complementary satellite, aircraft, ship, and in situ observations. We are concerned not only with the development and unambiguous physical interpretation of remote sensing techniques, but also with interfacing these techniques and data with a comprehensive research program involving data collection, analysis and interpretation.

Recent accomplishments in the area of observations include: establishment that the accuracy of chlorophyll concentrations derived by the Nimbus-7 Coastal Zone Color Scanner (CZCS) is nearly equivalent to that obtained from ship-borne sampling (+ 30%) for open ocean waters, and demonstration of the capability and accuracies of measurements of water attenuation, phycoerythrin and chlorophyll fluorescence, and chlorophyll fluorescence efficiency using aircraft laser remote sensing.

Both satellite and aircraft techniques were used by NASA and National Science Foundation (NSF) Warm Core Ring investigators to establish the distribution of chlorophyll and its temporal changes in and around warm core eddies. These data were used to improve shipboard sampling strategies and data interpolation. CZCS chlorophyll and AVHRR thermal data were used to observe circulation patterns and quantify current velocities in the rings experiment in the same manner wind velocities are derived from cloud measurements. We have seen significant advances in the application of CZCS data in fisheries science; albacore tuna catch and anchovy spawning success were correlated with CZCS-derived chlorophyll patterns off the west coast, and off the east coast CZCS data were used for marine ecosystem classification. The processing of raw data to level one products has been streamlined to the point where output rate is slightly greater than collection rate (280 scenes/week). This should decrease the amount of backlogged data.

Major thrusts in Fiscal Year 1983 include further streamlining satellite data processing, and increasing the accessibility of CZCS data. This includes the development of correlated color and temperature time series for selected U.S. coastal regions. Development of algorithms for addressing turbid waters continues, aided by the refinement of sensor calibration correction schemes. Application of laser technology for aircraft, shipboard and towed platforms will continue, along with research aimed at exploring measurements of fluorescence yield to improve estimates of biomass specific productivity. A workshop to intercompare various satellite sea surface temperature measurements is underway, and work continues on the accuracy of laser Raman and Brillouin scatter techniques for temperature and salinity. Greater attention will be given to theoretical modelling to address specific regional phytoplankton dynamics problems and the interfacing of data sets from complementary platforms.

## Polar Oceans Program

The goals of this program are to use spaceborne sensors to determine the characteristics of the polar sea ice cover, and to understand how sea ice is influenced by, and in turn influences, the atmosphere and ocean. Our immediate objective is to improve our capability of measuring from space the extent, type, movement, and surface characteristics of the sea ice cover. This involves detailed analysis of existing data from Seasat and the Nimbus series of spacecraft, airborne testing of new sensors, and collection and analysis of ground truth data from the ice surface. In addition, we are supporting modelling programs which address two distinct problems--improvement in our understanding of remotely-sensed data, and large-scale modelling of sea ice behavior. A major component of the program is to develop and assess interpretive algorithms for translating passive microwave data into estimates of sea ice concentration and surface characteristics. The multi-frequency SMMR on Nimbus-7 and SSMI on an upcoming DMSP mission show greatest promise, and data from these sensors have broad applications in both the scientific and the shipping community. Consequently, our studies are closely coordinated with associated NOAA and ONR research, and with Canadian investigators.

During the past year we completed the analysis of ESMR (Electronically Scanned Microwave Radiometer) passive microwave data over Antarctic sea ice, and we cooperated with Canadian scientists in an extensive Arctic field program. The field program yielded near-surface measurements of microwave radiation and radar backscatter, which can be related to simultaneous observations of ice characteristics. We have initiated a study to ensure rapid translation of SSMI data into sea ice parameters. Easy availability of these data to the research community will be achieved by prompt archival in the Pilot Ocean Data System (PODS) at JPL. We have also begun a study into potential scientific applications of SAR data from the European Space Agency's ERS-1 (ESA's Remote Sensing Satellite) over the Beaufort and Bering Sea regions collected by a proposed NASA receiving station at Fairbanks. Our sea ice modelling program has provided an insight on how the Weddell Polynya forms, and efforts are underway to incorporate a realistic model of the upper ocean. The SMMR, SAR, altimeter and scatterometer aboard Seasat each provided data that are affected by sea ice, and we are investigating the potential for enhancing data interpretation by intercomparing results from all these sensors.

During Fiscal Year 1983, we plan to continue these programs, and we shall publish an atlas of Antarctic sea ice for 1973-76 based on ESMR data. Conclusions of the SSMI and ERS-1 SAR study groups will also be published. In addition, we shall obtain surface and airborne passive microwave data during the Bering Sea MIZEX (Marginal Ice Zone Experiment) in conjunction with surface measurements of ice characteristics by ONR-funded researchers. We shall also examine detailed characteristics (floe size, lead orientation, and ice motion) derived from Seasat SAR imagery. Over the long term, we aim to refine the interpretation of passive microwave data sufficiently to permit archival of a self-consistent time series of sea ice parameters derived from Nimbus-7 SMMR and DMSP SSMI data. We shall continue to investigate the interactions between sea ice and the atmosphere and oceans, and much of this work will involve modelling studies. A major thrust will be towards acquisition of future SAR data from ERS-1 and from the proposed Canadian Radarsat. This will require both fundamental research into radar backscatter signatures from sea ice and detailed planning of a SAR receiving station in Alaska.

## Oceanic Flight Projects

The objective of the Oceanic Flight Projects effort is to develop and evaluate concepts for major flight experiments and supporting instruments that meet the observational requirements of the Oceanic Processes Program. Our major flight projects include TOPEX, which will support the needs of our Ocean Circulation program, the NROSS scatterometer, which will support the needs of both the Ocean Circulation and Air-Sea Interaction programs, and an Ocean Color Imager (OCI) to support the Ocean Productivity program. During Fiscal Year 1982, we developed a significantly lower cost mission implementation approach for TOPEX with only minor impact on performance. We also established the technical feasibility of flying a scatterometer on NROSS and the OCI on NOAA's operational meteorological satellite series (TIROS). Implementation approaches for both have been developed. Finally, we initiated the development and demonstration of an Advanced RF Tracking System (ARTS) that would utilize the Global Positioning System (GPS) to provide sub-decimeter quality orbit determination for TOPEX.

Areas of emphasis for Fiscal Year 1983 include initiating Phase B type detailed definition studies of TOPEX with industry in preparation for a possible Fiscal Year 1985 new start and initiating the development and demonstration of the 2-channel, high precision radar altimeter system capability planned for TOPEX. We will also refine the implementation approach and cost of flying a scatterometer on NROSS and an OCI on TIROS. Consummation of joint agreements with the Navy and NOAA, respectively, are required and are in process. Both are candidate Fiscal Year 1985 new start initiatives. The ARTS development and demonstration activity will continue, potentially leading to the successful completion of short baseline testing this coming summer.

## National and International Coordination

In the area of interagency coordination, aspects of the Oceanic Processes Program have been addressed during this past year by the National Academy of Sciences (NAS) and the National Advisory Committee on Oceans and Atmosphere (NACOA). A little over a year ago the NAS's Space Science Board/Committee on Earth Science published a report entitled, "A Strategy for Earth Science from Space in the 1980's--Part I: Solid Earth and Oceans." At the present time they are working on Part II which will address spacecraft observations for the cryosphere. During this past year the NAS's Ocean Sciences Board published a report entitled, "Two Special Issues in Satellite Oceanography: Ocean Dynamics and Biological Oceanography." The executive summary has been reproduced below:

> Satellites can provide unique, global data that, in combination with other *in situ* data, are likely to

> result in major advances in the ocean sciences. The two ocean-science fields most likely to be advanced through the use of satellite-acquired data are ocean dynamics (global ocean circulation) and biological oceanography.
>
> The highest priorities for a study of ocean dynamics from space are to measure the spatial and temporal variability of sea-surface elevation, to measure the mean sea-surface elevation relative to the geoid, and to determine the wind stress over the ocean. Such measurements are feasible only by using satellite technology, are required globally and at frequent intervals, and should last at least 3 to 5 years. Substantial supplemental *in situ* measurements will be needed in order to interpret and study the satellite data adequately.
>
> Understanding of important processes in biological oceanography can be advanced significantly by the application of satellite and other remote-sensing technologies via a coherent, long-term (5-10 years) program. A combined color/temperature scanner is an essential element of such a program. Supplemental aircraft-based and *in situ* sensors will be required in order to utilize and interpret the satellite data adequately.

During this past year, NACOA examined needs for a national civilian ocean sensing satellite program, and issued a position paper from which its summary has been reproduced below:

> The National Advisory Committee on Oceans and Atmosphere (NACOA) strongly urges the United States to commit itself to a national civilian ocean sensing satellite program and provide the resources necessary to proceed expeditiously with its development. Major, and potentially revolutionary, advances in the scientific understanding of ocean processes can provide significant benefits to public safety and our economy. Such advances cannot occur without the contribution of global and synoptic observations from ocean sensing satellites.
>
> The program concept to implement NACOA's recommendation should not be comprised of a special and independent series of satellites for carrying ocean measuring sensors. Rather, the program would consider the scientific requirements and

> incorporate relevant sensor needs into a national satellite effort integrated with other civilian satellite efforts. It would take into account and complement scientific information available through military satellite sensors as well as those of other nations. At present, however, a decision for a national program start--civilian or military--has been deferred until 1985. At the same time, several foreign efforts are underway, and we risk, not only a decay of our scientific leadership and potential benefit, but the loss of another field of technological leadership and opportunity to other nations.
>
> NACOA is concerned that cutbacks in scientific ocean research in the interest of economy might prove to be uneconomical and harmful to United States interests now and in the future.

In the area of international coordination, we continue to work with both the Joint Scientific Committee (JSC) and the Committee for Climate Change and the Oceans (CCCO), the work being focused on the determination of the role of the ocean in climate as part of the World Climate Research Program (WCRP). Organizationally, JSC falls under the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU), while CCCO falls under the Intergovernmental Oceanographic Commission (IOC) of the United Nations Education, Scientific, and Cultural Organization (UNESCO) and the Scientific Committee on Oceanic Research (SCOR) of ICSU. One principal component of the WCRP upon which we have centered our attention is the World Ocean Circulation Experiment (WOCE). Our potential contribution to WOCE would involve the utilization of satellite techniques (such as altimetry and scatterometry, discussed in Section II) to assist in a determination of the general circulation of the oceans, its effect on the redistribution of global heat, and the resulting influence on atmospheric climate.

Table 2 outlines national and international ocean spacecraft activities for the next decade, which are at various levels of planning and development. We are exploring potential areas of mutual interest with sponsors of these spacecraft. We are particularly interested in determining the extent to which it might be appropriate for us to pursue cooperative work. Depending on the needs of our community, we will be investigating options for obtaining access to data from these spacecraft and, for certain of them, the possibilities for flying one of our ocean sensors.

In conclusion, we would like to bring attention to a meeting of the Ocean Principals Group which the NASA Administrator, Mr. James M. Beggs, hosted this past July 13. (The Ocean Principals comprise the heads of the various ocean-oriented agencies.) At this meeting Mr.

Beggs discussed with agency heads the need to identify mutual requirements of observations of the oceans and to develop a coordinated program to meet them. Navy, NOAA, NSF, and NASA, in the meantime, have been planning elements of such a program. NROSS (a Navy program utilizing a NOAA bus and NASA scatterometer), the NASA/NOAA Ocean Color Imager (NOAA satellite, NASA instrument), TOPEX, and the NASA add-on to the NOAA Alaskan station for direct readout of the SAR aboard the ESA's ERS-1 satellite are facets of the program. To assist in preparation of the NASA Fiscal Year 1985 budget, Mr. Beggs has issued an invitation to the heads of Navy, NOAA, and NSF to meet with him this spring (late April/early May) so that he can see how well these elements meet agency requirements and the role that each agency plays in developing such a coordinated program.

## Table 1. NASA Science Working Groups

| Science Working Group | Chairman | Established | Report |
|---|---|---|---|
| SSMI Sea Ice Research Science Working Group | Norbert Untersteiner, U. Wash. | June 1982 | June 1983 |
| ERS-1/SAR Sea Ice Study Team | Gunter Weller, U. Alaska | April 1982 | June 1983 |
| Satellite Ocean Color Science Working Group | John Walsh, Brookhaven | October 1981 | March 1983 |
| In-Situ Science Working Group | Russ Davis, Scripps | September 1981 | June 1983 |
| Satellite Surface Stress Team (S-Cubed) | James O'Brien, FSU | July 1981 | July 1982 |
| NASA FIREX Ocean Study Team | Owen Phillips, JHU | March 1981 | June 1982 |
| NASA FIREX Ice Study Team | Wilford Weeks, CRREL | December 1980 | June 1982 |
| NOSS Science Working Group | Francis Bretherton, NCAR | May 1980 | November 1981 |
| TOPEX Science Working Group | Carl Wunsch, MIT | February 1980 | March 1981 |
| ICEX Science Working Group | Bill Campbell, USGS | February 1979 | January 1980 |

Table 2. Ocean-Related Spacecraft Planned for the Next Decade

| Satellite | Sponsor | Ocean-Related Sensors/Comments | Launch | Status |
|---|---|---|---|---|
| DMSP | USAF | MR | 1984 | Approved |
| | NASA | MR Data Processing Facility | | Proposed |
| GEOSAT | USN | ALT | 1984 | Approved |
| NOSS | USN/NOAA/NASA | ALT, CS, MR, SCAT | 1986 | Cancelled |
| MOS-1 | Japan | CS, IR, MR | 1986 | Approved |
| NOAA-H,I | NOAA | IR | 1987 | Approved |
| | NASA | Contribute Piggyback CS | | Proposed |
| SPOT-2,3 | CNES | Piggyback ALT | 1987 ? | Proposed |
| ERS-1 | ESA | ALT, SAR, SCAT, IR | 1988 | Approved |
| | NASA | SAR Data Receiving/Processing Facility | | Proposed |
| TOPEX | NASA | ALT + Option for SCAT | 1988 ? | Proposed |
| NROSS | USN | ALT, MR, SCAT | 1988 ? | Proposed |
| | NOAA | Contribute Bus (NOAA-D Spacecraft) | | Proposed |
| | NASA | Contribute SCAT | | Proposed |
| ERS-1 | Japan | SAR | 1988 ? | Proposed |
| | NASA | Utilize SAR Data Facility | | Proposed |
| GRM | NASA | Satellite-to-Satellite Tracking | 1989 ? | Proposed |
| ERS-2 | ESA | ALT, SAR, SCAT ? | 1989 ? | Tentative |
| RADARSAT | Canada | SAR | 1990 ? | Proposed |
| | NASA | Contribute Launch & Piggyback SCAT | | Proposed |
| MOS-2 | Japan | ALT, CS, MR, SCAT | 1990 ? | Tentative |

### ACRONYMS
(to accompany Table 2)

| | |
|---|---|
| ALT | ALTIMETER |
| CNES | FRANCE'S NATIONAL CENTER FOR SPACE STUDIES |
| CS | COLOR SCANNER |
| DMSP | DEFENSE METEOROLOGICAL SATELLITE PROGRAM |
| ERS-1 | ESA'S REMOTE SENSING SATELLITE #1 AND JAPAN'S EARTH RESOURCES SATELLITE #1 |
| ESA | EUROPEAN SPACE AGENCY |
| GEOSAT | GEODETIC SATELLITE |
| GRM | GEOPOTENTIAL RESEARCH MISSION |
| IR | INFRARED RADIOMETER |
| MOS-1 | MARINE OBSERVATIONAL SATELLITE #1 |
| MR | MICROWAVE RADIOMETER |
| NOSS | NATIONAL OCEANIC SATELLITE SYSTEM |
| NROSS | NAVY'S REMOTE OCEAN SENSING SYSTEM |
| SAR | SYNTHETIC APERTURE RADAR |
| SCAT | SCATTEROMETER |
| TOPEX | OCEAN TOPOGRAPHY EXPERIMENT |

# SPACEBORNE OCEAN-SENSING TECHNIQUES
(to accompany Table 2)

ALTIMETER - a pencil beam microwave radar that measures the distance between the spacecraft and the earth. Measurements yield the topography and roughness of the sea surface from which the surface current and average wave height can be estimated.

COLOR SCANNER - a radiometer that measures the intensity of radiation emitted from the sea in the visible and near-infrared bands in a broad swath beneath the spacecraft. Measurements yield ocean color, from which chlorophyll concentration and the location of sediment-laden water can be estimated.

INFRARED RADIOMETER - a radiometer that measures the intensity of radiation emitted from the sea in the infrared band in a broad swath beneath the spacecraft. Measurements yield estimates of sea surface temperature.

MICROWAVE RADIOMETER - a radiometer that measures the intensity of radiation emitted from the sea surface in the microwave band in a broad swath beneath the spacecraft. Measurements yield microwave brightness temperatures, from which wind speed, water vapor, rain rate, sea surface temperature, and ice cover can be estimated.

SCATTEROMETER - a microwave radar that measures the roughness of the sea surface in a broad swath on either side of the spacecraft with a spatial resolution of 50 kilometers. Measurements yield the amplitude of short surface waves that are approximately in equilibrium with the local wind and from which the surface wind velocity can be estimated.

SYNTHETIC APERTURE RADAR - a microwave radar similar to the scatterometer except that it electronically synthesizes the equivalent of an antennae large enough to achieve a spatial resolution of 25 meters. Measurements yield information on features (swell, internal waves, rain, current boundaries, and so on) that modulate the amplitude of the short surface waves; they also yield information on the position and character of sea ice from which, with successive views, the velocity of sea ice floes can be estimated.

# SECTION II - PROJECT AND STUDY SUMMARIES

| Project/Study Name | Author | Page |
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## NIMBUS-7 OBSERVATORY

Dr. Albert J. Fleig, Jr., Project Scientist, GSFC
Code 910.2, Greenbelt, MD 20771, 301-344-9136

The Nimbus-7 Observatory Satellite, launched on October 23, 1978, carried two (2) instruments which provide measurements applicable to research into oceanic processes: the Coastal Zone Color Scanner (CZCS); and the Scanning Multichannel Microwave Radiometer (SMMR). Both instruments have provided continuous measurements since initial activation and have exhibited no serious degradation in performance as of the end of the fourth year of operation.

### COASTAL ZONE COLOR SCANNER (CZCS)

Ed Szajna, GSFC, Code 910.2, 301-344-6979

The objective of the CZCS experiment is to determine the contents of water quantitatively over large areas in short periods of time. CZCS discriminates between organic and inorganic materials in open water, determines the quantity of the materials in the water sample and identifies organic particulates, such as various types of red tide organisms.

CZCS collects approximately 15,000 two-minute scenes per year of screened data after deleting scenes with excessive cloud contamination. There are approximately 20,000 scenes of Level-1 (Calibrated Radiance Tape) data archived with the NOAA Environmental Data Information Service (EDIS). Level-2 products have been produced and archived for 300 of these scenes. Many "Sea-truth" cruises have been conducted with coincident Nimbus-7 over pass data collected and validation studies performed. These show that pigment and diffuse attenuation coefficients calculated from CZCS measurements are well within the accuracy goals set for all but cases of high pigment concentrations for Level-2 products.

Archival of the Level-1 products for the first year of operation was completed in June 1982, and the second year will be completed in September 1983. Level-2 products for 500 scenes selected from the first three years of data will be available by April 1983. Additional Level-2 products are planned in subsequent years. An atlas will be prepared and archived in EDIS in 1983 with commentary on selected Level-2 scenes for U.S. coastal waters and open ocean areas.

Several significant contributions to both oceanographic and atmospheric optics have been published as has a Nimbus-7 Data Plan, Nimbus-7 User's Guide, and a CZCS data catalog.

## SCANNING MULTICHANNEL MICROWAVE RADIOMETER (SMMR)

Paul Hwang, GSFC, Code 910.2, 301-344-9137

Sea surface temperature, water vapor and wind speed over oceans, sea ice concentration, multi-year ice fraction, and a "snow parameter", all derived from SMMR measurements, are now available from the National Space Science Data Center (NSSDC).

Based upon intercomparisons between several data months of SMMR retrieved parameters and conventional surface measurements over open ocean areas, the rms accuracies for the ocean/atmosphere parameters are as follows: sea surface temperature, ± 1.6K; atmospheric water vapor, ± 0.25 $gm/cm^2$; and near sea surface wind speed, ± 2.5 m/sec. Due to the relatively large sensor "footprint" (150 km) and the effects of land contamination, the sea surface temperature measurements are restricted to areas more than 600 km from shore. Sea ice concentration and multi-year ice fraction algorithms meet their prelaunch goals of ± 5% accuracy for ice concentration and ± 15% accuracy for multi-year ice fraction.

The data is available in computer compatible tape and hard copy picture formats. A Nimbus-7 year 1, Level II Data User's Guide will be available in June 1983.

Upgrading of the geophysical algorithm is being done as data is being validated. The calibration procedure is being upgraded and will be implemented for the processing of year 3 data.

Data for 1980 and 1981 will be archived by November 1983.

## TIROS-N/NOAA SERIES

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Project Objectives: 1) To provide spectral radiometric information for more accurate sea surface temperature mapping and day/night cloud cover information. Also to provide higher accuracy and yield of atmospheric vapor soundings over the oceans. 2) To provide a remote platform location and data collection capability over the oceans.

Instrumentation:

1) Advanced Very High Resolution Radiometer (AVHRR)
   This scanning radiometer (4-channel on NOAA-6 and 5-channel on NOAA-7) provides stored and direct readout of radiometric data. The fifth channel was added to NOAA-7 to account for boundary layer water vapor and thereby increase the accuracy of sea surface temperature measurement in the tropics.
2) TIROS Operational Vertical Sounder (TOVS)
   This sounder consists of three instruments: a High Resolution Infrared Radiation Sounder (HIRS/2), a Stratospheric Sounding Unit (SSU), and a Microwave Sounding Unit (MSU). These instruments will provide better temperature and humidity soundings than previous sounders: the MSU measures the atmospheric temperature even in the presence of clouds. In addition, other parameters such as sea/land surface temperature, sea ice extent, and cloud cover can be determined from these sounders.
3) ARGOS/Data Collection System (ARGOS/DCS)
   This system, provided by France, is designed to locate, collect and relay data from free-floating balloons, buoys, floating ice platforms, remote weather stations, etc.
4) Space Environment Monitor (SEM)
   The objectives of the SEM are to determine the energy deposited by solar particles in the upper atmosphere and to provide a solar warning system.
5) Search and Rescue (SAR)
   SAR will be launched on NOAA E. Its purpose is to receive and locate distress signals from ships and planes.

Current Status: NOAA-7 (launched in 1981) replaced the original TIROS-N (launched in 1978). This satellite operates concurrently with NOAA-6 (launched in 1979). The NOAA-7 is in a 1430 LST ascending orbit, while NOAA-6 is in a 0730 LST descending orbit at the equator. Both are in sun-synchronous orbits at an average altitude of approximately 830 km, with orbital periods of 102 min. NOAA-6 will be replaced by NOAA E sometime after March 1983. NOAA E, like NOAA-6, contains the four channel AVHRR.

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Data Availability: Data from the AVHRR are available in 4 modes: 1) Direct readout to APT ground stations, 2) Direct readout to HRPT ground stations, 3) Global onboard recording readout to NOAA-NESDIS at Suitland, MD, and 4) Readout of onboard recording selected highest resolution (LAC) data. AVHRR and TOVS data are archived at NOAA/SDSD, World Weather Building, Camp Springs, MD. The data are available in two forms: level Ib calibrated radiance data, and level II retrieval products data, from February 1979 to present. Both tapes and picture imagery are available on request.

## ALTIMETRY

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Under the title Ocean Topography Experiment (TOPEX), NASA has been studying the requirements and implications for future altimetric satellite missions. The studies have been based upon experience obtained with altimeters flown previously on the GEOS-3 and SEASAT missions (collections of papers describing results of these missions may be found in Journal of Geophysical Research, 84, B8, 1979 and 87, C5, 1982).

From these studies, it is widely recognized that high accuracy and precision altimeters flown on satellites in appropriate orbits have major (possibly revolutionary) implications for marine geodesy, marine geophysics, physical oceanography and for certain operational purposes. The major impact of future appropriate missions would be in the physical oceanographic area - for the first time, oceanographers would be able to observe and understand the global ocean circulation and its changes. Such observations would have immediate consequences for the understanding of global climate and its changes, for understanding the oceanic reaction to the increase in atmospheric carbon dioxide, for understanding and predicting fisheries and the routes of dispersal of radioactive wastes. In addition, there would be immediate military and civilian operational benefits (e.g. in the areas of wave and acoustic forecasting).

In order to take advantage of an altimetric mission, the international oceanographic community has begun formulating a major global experiment - the World Ocean Circulation Experiment (WOCE). This program has the ambitious goal of establishing a global ocean observing system, of which one or more altimetric satellites would be the center-pieces. It is envisioned to occur over a 5 year period beginning in the late 1980's.

A complete study of the requirements for an altimetric mission has been completed (TOPEX Science Working Group, 1981). Engineering of a mission design has also been finished and the project now awaits NASA management go-ahead to construct and fly an appropriate satellite. In parallel with these studies, work continues on analyzing the SEASAT and GEOS-3 data sets in order to understand best how to use altimetry data and for the best design of WOCE. Studies published or in press demonstrate the determination of the marine geoid, of the large scale dynamic topography of the ocean, of the variability and the variability spectrum of the mesoscale in the ocean.

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# COLOR RADIOMETRY

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As a result of the launch of the Nimbus-7 Coastal Zone Color Scanner (CZCS) in October 1978 and the subsequent progress with data analysis, it is now possible to determine ocean chlorophyll concentrations from space to better than ±30% of in situ values in waters of little sediment or humic matter. The Satellite Ocean Color Science Working Group was established in October 1981 to consider the scientific utility of repeated satellite measurements of ocean color. The Working Group consists of J. Walsh, Chairman (Brookhaven National Laboratory), W. Barnes (Goddard Space Flight Center), O. Brown (University of Miami), K. Carder (University of South Florida), D. Clark (National Environmental Satellite Service), W. Esaias (National Aeronautics and Space Administration), H. Gordon (University of Miami), R. Holyer (Naval Ocean Research and Development Activity), W. Hovis (National Environmental Satellite Service), R. Kirk (Goddard Space Flight Center), R. Lasker (National Marine Fisheries Service), J. McCarthy (Harvard University), M. McElroy (Harvard University), J. Mueller (Naval Postgraduate School), M.J. Perry (University of Washington), and R. Smith (University of California). During 1981-82, the Working Group met 3 times to discuss major scientific problems which may be addressed with the use of future ocean color sensors from space-craft. The results of these activities are being published by the Goddard Space Flight Center as a report, The Marine Resources EXperiment (MAREX) Program, which will be available in early 1983. The consensus of the Working Group was that significant questions and problems concerning the amount of global primary productivity and its fate in terms of fishery yield or carbon storage of the ocean could be addressed and solved with a combination of future measurements from satellites, planes, moored instrumentation, and ships in a series of multidisciplinary experiments. The Working Group is now examining past CZCS data sets in order to specify in more detail the sampling design, logistics, and data reduction requirements of such experiments.

# IN SITU DATA COLLECTION SYSTEMS

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The In situ Ocean Science Working Group was established to address the following questions:

1. What are candidate problems and experiments that can be studied using satellite relay of in situ data and the satellite location of its source?

2. What improvements in relay and location systems are required to meet the needs of these experiments?

3. What, if any, new in situ sensors need to be developed to exploit data relay capability and support important experiments?

4. What are the options on accuracy, data rate, location ability, and revisit time to satisfy the major classes of scientific user?

5. What are the benefits to others, such as commercial users, operational forecasters, meteorologists, climatologists?

The Working Group has prepared an incomplete draft report in which a large number of the uses of satellite data relay and platform location are described. They concluded that no revolutionary in situ system are needed to exploit satellite capabilities, but rather outlined a number of avenues along which progress is being made in this direction and should continue.

The Group also summarized the requirements placed on satellite data relay and positioning systems by the oceanographic uses now envisioned. Completion of the Working Group report awaits the results of a study into the data capacity achievable with the ARGOS system. These results will permit determination of the adequacy of the present combination of ARGOS and GOES and lead to recommendations on any changes to future versions of these systems.

# SAR STUDIES OF SEA ICE IN ALASKAN WATERS

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## Introduction

It is generally agreed that the sensor with the greatest potential for sea ice studies is synthetic aperture radar (SAR). Sea ice features are characterized by a wide range of scattering coefficients so that good contrast exists between old ice, new ice and open water. Also SAR has high resolution, usually 10-100 meters, permitting the classification of ice in a given image and tracking of small features in sequential images. The table below shows the usefulness of SAR data in interpreting sea ice characteristics.

| Sea ice characteristics | SAR data |
|---|---|
| Extent | Good |
| Movement and deformation | Good |
| Snow cover | Not Known |
| Ice thickness | Some |
| Internal geometry (floe size, lead patterns) | Good |
| Surface roughness | Good |
| Ice types | Some |
| Physical properties (temp., salinity, strength, etc.) | Some |

A drawback of spaceborne SAR is that the associated data flow rate is so high that data cannot be stored on a satellite for playback while over a receiving station. This means that if one wishes to receive SAR imagery of important areas of sea ice, it is necessary to have a receiving station that is in range of the satellite while the satellite is viewing the sea ice. For the ice of the United States' territorial waters, such a site would clearly be in Alaska. Three satellites are currently under development which would deploy SAR systems in polar orbits: the ESA ERS-1 satellite, launch 1988; a Japanese satellite, launch 1987; and a joint Canadian/U.S. Radarsat, launch 1990. Data from all of these could be intercepted by an Alaskan station.

## Objectives

The objectives of the study presently underway are to examine the benefits of establishing an Alaskan receiving station for

SAR data, and to assess its potential in helping to solve scientific and operational sea ice problems.

## Potential Research and/or Operational Benefits

The geographical area which could be covered by an Alaskan receiving station includes a large variety of different sea ice settings and types which pose scientific as well as operational problems. Along Alaska's northern coast, the large-scale anticyclonic Beaufort Sea Gyre shears the sea ice, forming extensive regions of highly deformed ice over the continental shelf where intensive efforts in offshore petroleum exploration and extraction are just beginning. High velocity extrusion and break-out of ice through Bering Strait occur regularly into the Northern Bering Sea where a conveyer-belt type circulation advects ice out to the ice edge. The location of the ice edge is controlled by complex atmospheric and oceanic processes and may in turn partially control these processes.

Studies of these various ice regimes involve the disciplines of oceanography, meteorology and climatology and are concerned with the response of the ice to dynamic and thermodynamic forcing. Questions, for which answers are required include: What is the seasonal rheology of the pack ice? What are the heat, mass and momentum balances of the ice in the Beaufort Gyre, over the shelves and in the marginal ice zone? How does sea ice respond to climate changes and vice versa? What is the role of oceanic and meteorological features in the production, deformation and advection of ice in the Bering Sea and the Arctic Ocean?

Another set of questions can be asked in relation to engineering studies and in operational forecasting for ships in sea ice. What is the strength of annual and multi-year ice, pressure ridges and rubble fields? Where do these features occur seasonally? How do these ice types interact with offshore drilling platforms? Where can one efficiently route tankers through pack ice fields? When would invading ice threaten drillships operating in open water?

In summary, there seem to be numerous critical scientific and operational sea ice problems that could profitably be studied in Alaskan waters and for which a SAR station receiving sea ice data under all weather conditions is essential.

## Status of Project

A draft report has been prepared and is being reviewed prior to release in March 1983.

# SCATTEROMETRY FOR VECTOR STRESS MEASUREMENTS

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The Satellite Surface Stress Working Group was commissioned to suggest oceanic science that would be done if it were possible to determine the vector wind field at the sea surface. SEASAT demonstrated that it is possible to determine the wind speed and direction over the ocean to within very useful accuracies. While the oceanography community believes that it knows the relevant equations of motion for the ocean, it has never been capable of measuring the principal forcing function, the vector wind field, to calculate the ocean currents.

- The one unequivocal conclusion is that conventional wind data do not suffice to meet the research and application needs of the oceanographic community.

The required measurement is the vector horizontal tangential stress, which is the lower boundary condition for the atmosphere and the upper boundary condition for any wind-driven wave or ocean current model. It is recognized that considerable basic research will be necessary to interpret space measurements as vector surface wind stress.

The vector wind stress fields collected over the ocean will be used to drive a wide variety of ocean models. It will be possible to obtain quantitative estimates of upper ocean currents from these models. In the report we highlight a particular experiment known as the El Nino phenomena, because knowledge of the ocean variability may lead to the ability to forecast severe winters over the eastern United states up to a year in advance. Present ocean models indicate that previous El Nino events are excited by anomalous winds in the western Pacific. These winds excite an internal Kelvin wave which takes 2-3 months to reach the coast of Peru and disturb the local heat budget.

If our present ideas are correct, we should be able to make some predictions of El Nino if we measure the winds along the Pacific equator. For instance, the appearance of strong westerly winds would allow the forecast of an impending El Nino. If TOPEX were also in space we might be able to monitor the passage of the Kelvin wave as it moves eastward toward Ecuador. Verification of the existence of warm water off Peru would justify the initiation of plans for a severe winter over the eastern U.S. a few months later.

The vector wind stress fields are very important for many oceanographic problems. $S^3$ recommended that NASA proceed with a formal study of a system to meet the following minimum data requirements:

- An accuracy of 2 m/s or 10% (whichever is greater) in wind speed and ±20 degrees in wind direction as met by SASS and designed for NOSS must be maintained.

| Wind Speed | Requirements |
|---|---|
| < 3 m/s | None (Light and variable) |
| > 3 < 6 m/s | ± 2 m/s, ±20°, 100 km resolution |
| > 6 < 100 m/s | Larger of ±2 m/s, or 10% of wind speed, ±20°, < 50 km resolution |

- We require that the wind vector at 90% of the points at the equator and also at 35 degrees North be observed to within 50 km at least every two days.

- The antenna and polarization design must be sufficient to allow determination of a wind stress direction with no more than 2 direction ambiguities which are nearly 180° out of phase at least 90% of the time.

- The ability to detect atmospheric liquid water is an essential component of any scatterometer program. The minimum requirement is a flag for amounts of liquid water which hinder scatterometer accuracy.

- Data available in satellite orbit configuration are awkward to use as a global data set. Meteorologists and oceanographers are very familiar with weather data which have been mapped on to a latitude-longitude grid for a fixed time. This is called earth-gridded data. If the data are stored in a 3-dimensional matrix where the location in the matrix designates latitude, longitude and time, then the data are easily used for all purposes.

- Maximum time delay between observation and availability of gridded surface winds is 6 hours for operational use.

Scatterometer data are extremely valuable for applications other than oceanographic research, such as meteorological modeling, special naval ocean products and industrial use*. The impact of surface winds over the ocean on naval or industrial applications is sufficient to justify the investment in the scatterometer.

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* Scientific Opportunities using Satellite Wind Stress Measurements over the Ocean, Nova Univ. Press, 153 pp., 1982. (Available free from Ms. Jan Witte, Nova University, 8000 N. Ocean Drive, Dania, Florida 33004)

# MICROWAVE RADIOMETRY/SEA ICE

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Passive microwave remote sensing has been the only available and operational technique for obtaining all-weather, large scale images of sea ice. Most of the data base on ice extent obtained during the past decade and being used (among other purposes) for climate studies, was obtained by that method. Useful frequencies lie between about 19 and 90 GHz, with 37 GHz having been used operationally for routine mapping of ice extent and concentration. The spatial resolution of 25 km poses a limit to the detailed study of sea ice dynamics; however, the images obtained by ESMR and its follow-on instrument SMMR (since December 1978) have been used not only for mapping but also for studying excursions of the ice boundary related to storm systems and for monitoring such features as the Weddell Sea Polynya. The large difference between the apparent brightnesses of unfrozen and frozen sea water allow estimates to be made of the percentage of open water in each pixel, regardless of the type of ice present.

Sea ice is usually a mix of blocks and plates of different thickness and age. Dissolved and solid salt inclusions, air bubbles, crystal fabric, and a locally variable snow cover affect the apparent brightness in more subtle ways, making the interpretation of passive microwave images both more difficult and more informative of the physical state of the ice. Considerable progress has been made in distinguishing first-year from multi-year ice. The first year (1979) of SMMR data has been processed and is available in geophysical units and geographical coordinates. The algorithm used to derive ice concentration and first-year/multi-year fractional coverage is based on numerous field studies by aircraft and on the ground but will require further experimental refinements. Time series of maps showing the distribution of ice concentration and fractional coverage by certain ice types, combined with ice displacements observed by means of drifting buoys, will provide an essential data base for calculations of the mass balance of the arctic and antarctic sea ice covers. While the data buoy network and its surface pressure data is adequate for resolving the atmospheric pressure and wind field, the further study of the internal dynamics of the ice will require a much higher spatial resolution, as first demonstrated by means of sequential LandSat images. Similar tests with the small amount of data available from SeaSat indicate that the most desirable combination of measurements will have to include data buoys, passive microwave images, and synthetic aperture radar images.

# TIROS-N SCATTEROMETER AND OCEAN COLOR IMAGER

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During Fiscal Year 1982, Conceptual Design Studies were conducted to integrate ocean instruments into the NOAA Operational Polar Orbiter Satellites. Specifically, these included a Scatterometer for measuring surface wind stress on NOAA-J, and an Ocean Color Imager (OCI) for chlorophyll concentrations and diffuse attenuation coefficients on NOAA-H.

Scatterometer and radiometer design configuration changes were required to fit into the Advanced TIROS-N (ATN) weight, power, data, command, and volume allocations. The Scatterometer and radiometer designs, which were on the NOSS type instruments, were redesigned by the General Electric Co. and the Ball Aerospace Division, respectively.

Spacecraft subsystem changes were required to accomodate both the Scatterometer and radiometer. These changes (which included system configurations, power system modifications, command, and data handling changes) were examined by RCA, the TIROS prime contractor.

Langley Research Center personnel also conducted Scatterometer instrument performance evaluations and measurement system simulation studies. The Langley activities will be completed in mid-FY 1983 with the results to be reported in appropriate scientific journals. Lead center responsibilities for the Scatterometer were terminated at Langley in FY 1982 and have been transferred to JPL.

The Ocean Color Imager studies were carried through completion of a Phase A conceptual design. A final report has been completed and will be distributed in early 1983. Detailed studies of each major OCI system element (instrument, spacecraft, NOAA satellite command, control and data handling system, data flow, and the NASA ground processing system) have been completed. The Ball Aerospace Division conducted the conceptual instrument design study. The OCI baseline instrument is a 10 bit - 8 channel visible/near IR scanning imager. Since a thermal channel is available from the AVHRR (Advanced Very High Resolution Radiometer) on NOAA-H, none is included in the OCI baseline.

RCA/AE conducted an instrument accomodation study for the TIROS ATN satellite. With minor spacecraft modifications, the TIROS ATN can accomodate the OCI instrument and associated data handling system to provide the following capabilities:

a) Global coverage (4 km) recorded on tape for playback at a NOAA CDA (Command and Data Acquisition) station.

b) Local coverage (1 km) 10 minutes/orbit recorded on tape for playback at CDA stations and real time direct broadcast whenever the instrument is operating.

OAO Corporation conducted an OCI data flow study to define impacts on the NOAA CDA/SOCC (Command and Data Acquisition/ Satellite Operations Control Center) ground system and operations. Results of the study showed that software modifications are required to identify and schedule OCI operations. However, by using a data format and rate similar to those associated with the AVHRR instrument, the OCI output would have a minimal impact on CDA and direct readout stations. All taped data will be transferred from CDA to GSFC via DOMSAT for production processing at a dedicated OCI processing facility.

An in-house ground processing system study defined the need for a dedicated OCI production processing facility. The study also defined the need for an assessment, validation, and scientific user interface facility. Emphasis has been placed on timely data processing and convenient scientific user interfaces. NASA will produce Level I and Level II chlorophyll concentration and diffuse attenuation coefficient data sets, as well as global maps and monthly summaries. All OCI data will be archived at NOAA/NESDIS (National Environmental Satellite and Data Information Service, formerly EDIS) for general distribution.

# OCEAN TOPOGRAPHY EXPERIMENT (TOPEX)

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Program Science Objectives: The primary objective of the Ocean Topography Experiment Program is to measure the sea surface topography of the ocean over entire ocean basins for a period of several years. These measurements will be integrated with subsurface measurements and models of the ocean's density field in order to determine the general circulation of the ocean and its variability. This information will then be used to: 1) understand the nature of circulation dynamics, 2) calculate the heat transported by the oceans, 3) observe the interaction of currents with waves and sea ice, and 4) test the ability to predict circulation from wind forcing.

Instrumentation: The objectives of TOPEX require that the satellite height above the sea surface be measured and combined with satellite orbit information. The first measurement is to be made by a satellite-borne radar altimeter derived from those flown on Skylab, Geos-3, and Seasat. The TOPEX altimeter will operate at two different frequencies to correct height measurements for the total ionospheric electron content. A three-channel microwave radiometer will gather data required for atmospheric water vapor correction. Orbit information will be determined from intensive tracking of the satellite by the Defense Mapping Agency's Tranet System. A second tracking system, an Advanced Radio Metric Tracking System (ARTS), may aid the orbit determination process if experiments are successful. Verification of both measurements will be made through laser tracking of a laser retroreflector carried on the satellite.

Current Status: TOPEX conceptual studies were carried out from February 1980 through September 1982. The baseline mission selected an orbit altitude of 1334 km circular, inclined 63.4° in order to avoid aliasing tidal components into the topography. The orbit will provide an exact 10-day repeat coverage of the global ocean for at least three years.

During Fiscal Year 1982: 1) a broad cost-effectiveness study was performed to insure that the baseline mission provided balance among performance, cost, and risk, 2) an assessment of tracking methods for precision orbit determination given expected gravity field knowledge led to the selection of TRANET, 3) altimeter performance analyses and frequency selection studies were carried out, 4) a demonstration test program was begun for ARTS, and 5) industry studies indicated the feasibility of modifying an existing design earth satellite for the TOPEX mission. System definition studies are planned to be conducted in Fiscal Year 1983, leading to Project authorization in Fiscal Year 1985 and and launch in the fall of 1988. TOPEX is expected to be a key contributor to the World Ocean Circulation Experiment (WOCE) planned by the international oceanographic community for the latter part of the decade.

Data Availability: TOPEX will produce three classes of data: the first includes operational data required for satellite control and a limited set of raw data which could be made available for operational users; the second is an interim data record containing preliminary corrections, available about five days after acquisition; and the third is a full geophysical record of the data with all corrections applied, available within six months of acquisition. Distribution of the data will be through the Pilot Ocean Data System, which is currently providing access to Seasat data for six oceanographic institutions in a demonstration program.

Additional Information Sources: For a brief overview of the TOPEX program and the scientific questions it addresses, see JPL 400-133, TOPEX, Observing the Oceans from Space, Jet Propulsion Laboratory, Pasadena, California, July 1982. The science rationale is addressed in JPL 400-111, Satellite Altimetric Measurements of the Ocean, Report of the TOPEX Science Working Group, Jet Propulsion Laboratory, Pasadena, California, March 1981.

Detailed information on the TOPEX mission and systems is available in 1633-1 Ocean Topography Experiment (TOPEX) JPL Study Team Phase A Report, Jet Propulsion Laboratory, September 1981 and JPL D-190, Ocean Topography Experiment (TOPEX) JPL Study Team Phase B Report, Jet Propulsion Laboratory, September 1982.

Program/Project responsibilities include: NASA Headquarters Environmental Observations Division, Oceanic Processes Branch; JPL, Project Management; GSFC/WFF, Altimetry; GSFC, Precision Orbit Determination.

# OCEAN SCATTEROMETRY PROGRAM/ NROSS ACCOMODATION STUDY

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The objective of the Ocean Scatterometry Program is to develop a spaceborne scatterometer capable of meeting the science requirements set forth by the NASA Satellite Surface Stress Working Group, and to conduct research and experiments leading to a better understanding of the relationship between radar reflectivity and wind velocity. In FY 1983, our primary objective is to support the development of a scatterometer to be flown on the Navy's Remote Ocean Sensing System (NROSS) satellite. We will verify and refine scatterometer system design softwares and perform detailed system analysis and simulation studies for a scatterometer on NROSS. The achieved wind velocity accuracy as well as the ability to remove wind direction ambiguities will be evaluated. We will conduct subsystem tradeoff studies such as in the use of digital vs. analog filters. The results from these studies will be incorporated into an optimal scatterometer design. The design of the ground processing system will also be examined. A proposal consisting of system designs, schedules, and cost estimates will be submitted for an FY 1985 new start.

Another objective in FY 1983 is to carry out research which leading to an improved geophysical model relating radar backscatter to wind velocities. We will continue the analysis of Seasat SASS data for a detailed examination of any systematic errors. We will also examine existing aircraft scatterometer data for similar errors. The results will be used to plan future experiments for model improvement.

This program was initiated in February 1983.

# ERS-1/SAR

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The European Space Agency (ESA) is planning to launch an Earth Resources Satellite (ERS-1) in 1987 with a SAR as part of its payload. The SAR will operate at C-band, and will have characteristics similar to the Seasat SAR. The satellite will be in a near-polar orbit.

This preliminary study investigated the possibility of modifying the NASA Fairbanks receiving station to allow reception of the ERS-1 SAR data. This will allow acquisition of radar images over the Beaufort Sea, Bering Sea, Gulf of Alaska, State of Alaska, and northwestern Canada. The study also addressed the feasibility of processing 6 minutes of data within 24 hours of acquisition in order to conduct demonstration experiments. The processor will be located in Fairbanks and will be similar to the Interim Digital Processor presently in use at JPL. The remainder of the acquired data will be processed at JPL by the Advanced Digital SAR Processor (ADSP).

Data acquired over the Alaskan region will allow researchers to investigate the dynamic behavior of polar ice through at least one full year. Both local (particularly along the Alaskan Coast) and global dynamics are of interest for scientific and commercial purposes. The data will also provide some insight into wave-ice interactions in the ice margin zone. In addition, these data could be used for Earth resources research in Alaska, particularly with respect to geological mapping, forest inventory, river flood monitoring, and permafrost dynamics.

In FY 1983, a detailed science investigations plan will be prepared. An implementation plan for station modifications and the SAR processors will also be prepared.

# PILOT OCEAN DATA SYSTEM

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In response to the need for more effective access to satellite data sets, the Pilot Ocean Data System (PODS) is being developed at Jet Propulsion Laboratory. The objective of the system is to demonstrate techniques for the management and analysis of large satellite data sets for the ocean sciences. Complete geophysical data sets from the Seasat Altimeter, Scatterometer, and Microwave Radiometer (SMMR) have been compressed and stored in an on-line data system that provides rapid, selective access to data subsets selected by sensor, time, and location. A flexible, self-guided menu interface provides access for casual users to growing inventory of data mangement and analysis tools. An investigator can interactively examine a data-set catalog, search an on-line bibliography, browse through sample data sets, or apply assorted analytical tools to rapidly find a candidate data set and evaluate its utility for a specific application.

A relational data base management system indexes the very large satellite data files. Access to any desired segment of data can be obtained in minutes. In-situ data are managed directly by the system, as the volume is more modest. Seasat and correlative in-situ data now available require approximately 700 megabytes on-line and about 50 gigabytes on tape.

Graphics workstations are connected to PODS via a commercial communications network, and transmit data at 1200 bits/second. Data output is in the form of magnetic tape and printed listings; tabular and graphic displays are available at the user's terminal. Paper or magnetic tape products are shipped to investigators within 24 hours of generation via an express shipping service.

Future plans call for the acquisition of new data sets such as those from the Nimbus Microwave Radiometer (SMMR) and Coastal Zone Color Scanner (CZCS), Tiros Infrared Radiometer (AVHRR), and the DMSP Microwave Imager. Chlorophyll measurements from the CZCS and sea surface temperature measurements from the AVHRR will be used to construct time series data sets for three U.S. Coastal regions. These time series will have a temporal coverage of five or more years, allowing investigators to study the annual and interannual variability associated with mesoscale oceanic features. Data from the DMSP Microwave Imager will be used to construct daily, 25 km resolution ice extent and ice age maps for both polar regions. By the mid-1980's, the Pilot Ocean Data System is expected to support an on-line data base of 5 to 8 gigabytes and an off-line archive one to two orders of magnitude larger.

# SECTION III - INDIVIDUAL RESEARCH SUMMARIES

Individual research activities supported in full or in part by the NASA Oceanic Processes Program in Fiscal Year 1982 are summarized in the following pages. Short descriptions of activities initiated in Fiscal Year 1983 are also included. The activities are listed alphabetically by senior principal investigator. Thirteen investigations were jointly supported by NASA and other government agencies, including National Oceanic and Atmospheric Adminstration (NOAA, including NESDIS, NWS, and NMFS), Office of Naval Research (ONR), National Science Foundation (NSF), and Atmosphere Environment Service (AES) - Canada.

## STUDIES OF OCEAN PRODUCTIVITY

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Long-Term Interests: To understand the spatial and temporal variability of the amount and production rate of phytoplankton biomass and the relationship of such variability to physical forcing.

Specific Objectives: To relate the ocean color signal received by the Coastal Zone Color Scanner (CZCS) to the vertical and horizontal distribution of phytoplankton biomass and production rates, and to understand the coupling of physical and biological processes responsible for the temporal and spatial variability observed in CZCS and thermal imagery.

Approach: Satellite imagery will be compared with extensive field measurements of vertical and horizontal chlorophyll distributions and productivity with associated physical and optical data from three regions: Lake Tahoe, Calif.-Nev., the continental shelf off Vancouver Island, B.C. (both with Dr. K.L. Denman and Dr. T.M. Powell), and the Southern California Bight (with Dr. R.W. Eppley). The effects on CZCS-derived estimates of productivity of various processes such as vertical distributions and species composition, will be examined. We will also compare the spatial statistics obtained from the field data with those from the more complete series in the CZCS imagery. To investigate the coupling of biological and physical processes, we will compare thermal and color imagery using various statistics for all three areas as well as for the Coastal Ocean Dynamics Experiment (CODE) where an extensive set of color and thermal images as well as intensive physical measurements were collected. (This work will be jointly sponsored by NSF and NASA.)

Current Status: Satellite images of color and temperature have been identified and located for all four regions. Statistical analysis of field data from Lake Tahoe and Vancouver Island is nearly completed, and initial comparisons with satellite imagery will begin shortly. Similar analyses of the Bight will be started this year. Analysis of the CODE thermal images is being done by Kathryn Kelly (SIO), and preliminary comparisons between color and temperature have been made. Significant small-scale differences have been observed, particularly near the coast.

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# PILOT STUDY AND EVALUATION OF A SMMR-DERIVED SEA ICE DATA BASE

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The long term interests of the principal investigator concern large scale climate-cryosphere interactions and their significance for climate variability. Remote sensing data form a key tool for these analyses. The WDC-A for Glaciology/National Snow and Ice Data Center is developing archives of snow and ice data for the user community.

Objective: The objective of this activity is to provide an assessment of the Nimbus-7 SMMR-derived sea ice information by developing test products useful to the snow and ice community from the PARM-SS and MAP-SS data for 1979. User difficulties experienced in working with these data products will be documented.

Approach: SMMR ice products will be prepared, based on a survey of potential needs of the snow and ice community. This information, together with computer software developed to manage the data, will be used to generate graphical and tabular sea ice data products. These products will then be made available to the snow and ice community. To check the SMMR data, independent sea ice information from charts in the WDC-A will be compared to the SMMR data.

Current Status: Mark Anderson (Graduate Research Assistant) visited NASA Goddard Space Flight Center in August 1982 for discussions with SMMR team members. Sample SMMR tapes containing PARM-SS and MAP-SS data and their respective tape documentation were obtained. Anderson also participated in the SMMR Sea Ice Workshop, 28-29 October 1982. Initial software development for accessing the data using the NOAA National Environmental Satellite and Data Information Service (NESDIS, formerly EDIS) has begun. This includes hand conversions of the binary data to determine coverage periods and to understand the PARM-SS and MAP-SS data formats.

# SHORT TERM CRYOSPHERE-CLOUD INTERACTIONS NEAR THE SNOW/ICE LIMIT

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The long term interests of the principal investigator concern large scale climate-cryosphere interactions and their significance for climate variability. Remote sensing data form a key tool for these analyses.

Objective: The objective of this activity is to develop a matrix of cryosphere and cloud data that will provide a basis for 1) analysis of their synoptic-scale interactions, and 2) sensitivity testing of planetary albedo parameterizations in climate models (the latter is being performed under support from the National Science Foundation).

Approach: The approach is to utilize the US Air Force's DMSP (Defense Meteorological Satellite Program) 4 km resolution visible and IR imagery satellite data, supplemented as necessary by ground based observations and other data to determine cloud conditions in relation to snow cover and sea ice boundaries.

Current Status: Various case studies of cloud conditions across snow cover and sea ice boundaries have been analyzed. Synoptic models of cyclonic storms in middle and high latitudes have been developed using DMSP satellite imagery to classify the stage of development, and US Navy 'spot' data to calculate composite surface and upper air characteristics for each type of system. Both analyses have demonstrated significant relationships between the location of cryosphere boundaries, the nature of the overlying cloud cover, and the location and development of storm systems. All of the analyses originally proposed are nearing completion and several papers have been submitted. Some sensitivity testing of the planetary albedo parameterization of climate models has been performed in collaboration with A. Henderson-Sellers and K. Shine (University of Liverpool).

# THE INFORMATION CONTENT OF SPACEBORNE SYNTHETIC APERTURE RADAR OCEAN WAVENUMBER SPECTRA

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Long Term Interests: Application of spaceborne microwave sensing to major ocean research problems, and understanding of governing physics.

Specific Task Objective: Determine performance range over which Seasat SAR accurately measures dominant wavelength and direction; investigate relative strengths of various backscatter modulation mechanisms, and how they might be optimally utilized in future SAR oceanography missions.

Approach: Using 1) field measurements of spatially modulated short wave spectra, 2) digitally processed Seasat SAR data from pass 1339, and 3) a number of auxiliary surface, aircraft, and spacecraft measurements, perform cross-correlations of spatially and temporally coincident data and interpret in context of established or improved models.

Status: In the past year, a comprehensive set of digitally processed data from MacDonald Dettwiler and Associates (MDA) has been acquired which spans the entire 900 km along pass 1339. A master set of 147 two-dimensional Fourier transforms, contiguous along the entire pass, is now under intensive analysis to separate random and systematic (instrument-induced) artifacts from the real spatial variations of the spectrum. A definite azimuth wavenumber fall-off dependence upon local sea state has been identified which appears to confirm certain imaging models while rejecting others.

This work will continue in FY83, and will become more directed at specific oceanographic applications of the spatially evolving spectra. Related work is being sponsored by the Office of Naval Research, and by internal research and development funds.

# GULF OF MEXICO CIRCULATION STUDIES

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Long Term Objective of Investigators: The long term objectives of the investigators are to: (1) develop techniques for assimilating altimetric data into numerical circulation models, and to understand the effect of error in altimetric data on these models; (2) assess the relationship between altimeter sea surface heights and concurrently measured steric heights by comparison between altimetric and hydrographic mean surfaces.

Objectives of this Task: The objective of this task is to study the use of satellite altimetry together with wind data and in-situ data for the description of ocean circulation in the Gulf of Mexico. This research will answer fundamental questions regarding techniques for the assimilation of satellite and in-situ data into circulation models.

Approach: We plan to achieve our objectives through the use of Seasat and GEOS-3 altimeter data, together with available in-situ data in existing circulation models for the Gulf of Mexico.

Current Status: Progress to date has included the following. (1) Synthetic sea surface heights for the Gulf of Mexico have been generated using the NORDA reduced gravity model. Signatures commensurate with anticipated TOPEX error have been added to these data for use in sensitivity studies. (2) The GEOS-3 altimeter data have been placed on the Ocean Pilot Data System, and work is progressing toward development of a long-term altimetric mean sea surface for the Gulf of Mexico. (3) All in-situ data for the Gulf have been collected, and mean dynamic height surface has been produced. (4) A study has been performed using only sea surface height data and knowledge of the inflow to the Gulf through the Yucatan Strait to begin constructing the reduced gravity model. Results from this study compare favorably with results from the model utilizing complete information on velocity and thermocline depth.

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# AIR-SEA INTERACTION STUDIES FOR SATELLITE MEASUREMENTS

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Long Term Interests: We are investigating the relationship between marine winds, surface stress, and sea state in order to evaluate satellite microwave wind and stress measurement capabilities. Our long term interests include integrating this satellite microwave data into weather, pack ice, and ocean modeling.

Objectives: The objective of our current research is to study the relation between the scatterometer (SCATT) backscatter coefficient and the wind and sea state. We are using data taken from the NASA CV 990 airborne laboratory by L. Jones during the Storms Transfer Response Experiment (STREX) in conjunction with geophysical data taken from the NOAA P-3 and the NCAR Electra. We are also intercomparing Seasat SASS, JASIN, and MARSEN data sets. Our goal is to better understand the effects and responses of the SCATT to the disturbed sea state, particularly in the vicinity of mid-latitude cyclones, fronts, and small storm systems.

Approach: We are working in three related areas: the evaluation of simultaneous SCATT, wind, stress, heat flux, and visual data taken from the three aircraft during STREX; detailed theoretical and empirical studies of our air-sea boundary layer model near surface winds, aimed at improving the relation between wind and short wave sea state description; and collection and analysis of Seasat microwave data taken in mid-latitude cyclone regions to compare with STREX data.

Current Status: We are currently doing the final processing of the Electra data taken during STREX. Our Planetary Boundary Layer model was used to establish mean surface winds, stress, heat flux, divergence, and vertical velocity fields for all of STREX--a 2000 x 2500 km region daily at 00Z. A unique horizontal profile of heat and momentum flux variation across a strong Pacific front has revealed unusual variation in stress behind the front. This variation is closely related to the changing sea state. When the Electra data are satisfactorily reduced, we will explore all correlations with the SCATT data. Our emphasis is on obtaining accurate modeling in the near surface wind profile and establishing its connection to short ocean waves. We are collecting and evaluating STREX and other similar frontal data taken in conjunction with scatterometer data.

# RAPID SAMPLING VERTICAL PROFILER

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Our long-term interest with which this project deals lies in the exploration of the variability of the upper ocean and in the elucidation of the processes which govern the distribution of heat, salt and momentum in near-surface waters. The objective of this particular project is to develop an instrument system capable of producing profiles of oceanic variables, initially heat and salt, when deployed from a moving ship.

Our approach to this task involves a small probe connected to a thin line which provides both data link and retrieval mechanism. The probe falls at several meters per second, trailing the line behind it, and then is winched back to the ship. A high-speed digital data-acquisition system on board the ship records during descent. The probe is then retrieved and relaunched. A pressure signal is recorded as well as temperature and electrical conductivity, so that these variables can be plotted as functions of depth. Continuation of this process produces a map in two dimensions.

The second major test of the RSVP took place on a 23-day cruise of the R/V NEW HORIZON, 5-28 July 1982, from Honolulu to 42 N and back. Besides the RSVP, instrumentation included a towed thermistor/conductivity chain (Clayton Paulson, Oregon State University) and an Acoustic Doppler Shear Profiler (Lloyd Regier, Scripps Institution of Oceanography). The RSVP was deployed at 6-minue intervals for 7 hours each day while the ship proceeded at 4.2 knots. The RSVP penetrated the water column to 240 m on the typical cast. Sensors on the RSVP included a pressure transducer, a thermistor, and a conductivity sensor. A standard NBIS conductivity sensor was normally used, but on 3 of the days an extremely small "microconductivity" sensor was tested. Several types of thermistors, data links, power supplies, and data-transmission techniques were also tested. In data analysis and instrument autopsies a number of problems have been identified, but they can all be fixed without compromising our goals.

In the next year we plan to complete engineering and scientific analysis of the data obtained on the 1982 cruise, to integrate our profiles with the horizontal information provided by the towed chain and with the shear profiles, to solve the operational problems discovered on the 1982 cruise, and to prepare for the next major test in October-November 1983.

# APPLICATION OF REMOTE SENSING
# TO STATISTICAL STUDIES OF OCEANIC PROCESSES

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## Long-term interest of the Investigator

To develop the mathematical framework whereby data from a variety of sources, including satellites, aircraft, ships and buoys, can be utilized to estimate primary productivity on a global scale.

## Objective of this specific research task

To delineate specifically the role of aircraft in multiplatform experiments. Focus is on deriving information concerning biological processes, principally phytoplankton population dynamics, from radiometric measurements made by high-resolution passive and active aircraft remote sensors. Inferences are based on known effects of phytoplankton pigments, seston and dissolved matter on the light field in the upper mixed layer of the ocean.

## Approach utilized for this task

We compared simultaneous lidar (AOL) and passive color (MOCS) data collected over Nantucket Shoals in May 1981. Excellent agreement in their respective estimates of chlorophyll effected confidence in the empirically-derived yet poorly understood MOCS algorithm. If a firm basis for the MOCS algorithm could be established, then comparisons of the AOL chlorophyll fluorescence with MOCS chlorophyll might reveal information on fluorescence yield. To investigate the basis of the MOCS algorithm, our approach was to apply the algorithm to models of reflectance that contained explicit dependence on "chlorophyll-like" pigments, and in addition to examine extraneous effects (e.g., incident light, solar elevation, etc.) on the algorithm.

## Current status and progress

We were able to explain the effect of "chlorophyll-like" pigments on the MOCS algorithm and its relative insensitivity to extraneous variations in radiance. A manuscript detailing these results was submitted to Applied Optics in September 1982.

## Research support

This research was conducted at the NASA Langley Research Center as a part of the Nantucket Shoals Experiment, 1981-82.

## COUPLED ACTIVE-PASSIVE ANALYSIS

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Long Term Interests: I am interested in developing applications of remote sensing to research on science and operational problems regarding sea ice in the polar regions. Remote sensing methods are effective for observing many characteristics of sea ice, thus, these methods are powerful research tools. A most interesting and significant observational problem is to monitor the complete seasonal cycle of the pack.

Objectives of This Task: The objective of this task is to improve the interpretation of active and passive microwave remote sensing data for sea ice. The two methods have individual strengths and limitations. This research is designed to reduce overall interpretation limitations by applying collective measurement strengths. The focus is to improve the observational quality of aspects of the seasonal cycle of sea ice, including extent, type, concentration, albedo, snow cover, and velocity.

Approach: The approach is to examine the Seasat data set and data from Nimbus, Landsat, and other satellites. Initially, the types of analysis to be used are:

1) Overlap of different data types for visual correlation.
2) Seasonal changes (spring to summer to fall) in the emission and backscatter coefficients with concomittant changes in the ice cover.
3) Brightness and backscatter distribution analysis.
4) Comparison with surface data and aircraft data sets as available, principally from field work.

Current Status: This task began in FY 1982 with the establishment of software to utilize polar data from Seasat SASS and SMMR, with the development of techniques for overlaying SASS and SMMR data onto SAR images, and with the examination of altimeter pulse forms over sea ice. Work was also done on the efficient tracking of ice floes in sequential SAR images and on scene classification methods for SAR ice images. Papers on SAR ice feature tracking and altimeter studies of sea ice are in preparation.

## FIREX FIELD PROGRAM

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Long Term Interests: I am interested in developing applications of remote sensing to research on science and operational problems regarding the sea ice of the polar regions. Remote sensing methods are efective for observing many characteristics of sea ice, thus, these methods are powerful research tools. A most interesting and significant observational problem is to monitor the complete seasonal cycle of the pack.

Objectives of This Task: The objectives of this task are to perform the studies needed to establish satellite instrumentation requirements and to develop specifications for a high resolution imaging radar instrument and program for research on sea ice science and operations problems. Specifically these include:

1) Determination of the mean and variable components of microwave properties of significant sea ice species during the transition from spring to summer conditions, and during the summer.
2) Acquisition of a data set to contribute to fundamental understanding of the microwave properties of sea ice in the arctic summer.

Approach: The approach was to design and implement surface and helicopter supported examinations of active and passive microwave coefficients of the features of the ice pack in late spring and in summer. Four sites were examined in June-July, 1982, near the staging area of Mould Bay, NWT, Canada. These sites consisted of first year and old ice including ridges, hummocks, frozen leads, frozen melt-ponds, and varieties of snow cover.

Current Status: Data sets from the summer experiment are essentially completed. A data report is out, a meeting of participants is scheduled for January, and the goal of publishing scientific papers by October, 1983, is still on schedule. Starting with FY 1983, this work will be included under "Coupled Active/Passive Analysis".

# BERING SEA MARGINAL ICE ZONE PROCESSES AND REMOTELY-SENSED OBSERVATIONS

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Long-Term Interest: The long range goal is to improve the capability for making large-scale sea ice measurements from passive microwave space observations. Of particular interest is the extent to which high-frequency data can be used to remove ambiguities in distinguishing between various ice types thereby overcoming current limitations in ice concentration retrievals. These limitations are most acute in marginal ice zones which are characterized by rapid spatial and temporal ice cover variations.

Objective: The primary objective is the assessment of a wider range of passive microwave frequencies than is currently available from space for studying the definition of the ice edge and ice compaction in marginal ice zones. Observed variations in the position of the ice edge and in the amount of open water within the Bering marginal ice zone will be related to wind and ocean-swell forcing. This is expected to aid in the understanding of the relative importance of each of these oceanic processes in determining the ice edge zone characteristics.

Approach: The approach includes the acquisition and analysis of surface, aircraft, and satellite passive microwave observations of the Bering marginal sea ice zone in February 1983. The principal aircraft sensors are the passive microwave imagers at 19, 92 and 183 GHz and fixed-beam radiometers at 10.7, 18, 21 and 37 GHz on NASA's CV-990 airborne laboratory. Satellite observations by Nimbus-7 SMMR will complement the aircraft measurements by providing a large-scale overview of the entire experimental area.

Status: This task is new in FY'83. In a related study, Cavalieri et al. (1982) used sea ice concentration maps derived from the Nimbus-7 SMMR data to examine the Bering Sea ice cover during the March 1979 Bering field experiment. Through a comparison with surface, aircraft, and Tiros-derived ice charts, the study demonstrated that satellite passive microwave observations provide an improved description of the ice concentration variations in the Bering marginal ice zone compared to visible satellite imagery.

# A SATELLITE-LINKED OCEAN OBSERVING SYSTEM

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Scientifically, our interests include obtaining a more complete understanding of meso- to large-scale low frequency ocean circulation; technologically they include exploiting existing state-of-the-art technology to create the necessary tools to do so. These developmental activities are consistent with and form an integral part of an oceanic observing system concept (see R. Chase/Facilities for Oceanographic Remote Sensing Applications).

The objectives of this task are to obtain statistically reliable maps of various physical properties of the ocean. The requisite data should provide a new first-order kinematical description from which we expect to derive a more complete dynamical understanding of the linkages between small and large scales as well as the frequency dependence of temporally-averaged current fields.

Our approach to obtaining the desired subsurface horizontal sections relies upon developing a relatively low cost, general purpose relay system capable of reaching into the interior of the ocean and telemetering data from various depths, via a satellite-based data collection and location system (DCLS), to shoreside facilities. This new system is a generalization of satellite-linked drifting systems used in the last decade; it permits data acquisition over a much broader depth range, with more and diversified sensors, and with a nominal one-year lifetime. Major innovations include providing measurements from two underwater observational systems, implementation of on-board current meters, extending a total systems communicator protocol, and transmission of all underwater systems data via satellite. Initially we plan to acquire temperature, pressure, and velocity fields, the current velocity being obtained from acoustic signaling float observations and differential location of the relay system with satellite Dopppler DCLS records. On-board current sensors supply relative current velocities, providing a means for field calibrating the Lagrangian response of the drifter.

Presently we have completed both the systems and detailed engineering designs; construction of a prototype system consisting of decoupled surface float (with controller, DCLS transmitter, and power supply), subsurface electromechanical cable, and acoustic receiver has been completed. The first field trials to test both the electronic and mechanical components of the system are scheduled for December 1982.

# FACILITIES FOR OCEANOGRAPHIC REMOTE SENSING APPLICATION

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Many questions relating to meso- and large-scale ocean circulation might better be addressed with an observing system, closely akin to that which is available to the meteorological community. My long term interests include developing a tripartite observing system (utilizing remote sensing, Eulerian, and Lagrangian measurements) which could be used to gain a more complete description and understanding of large-scale, low-frequency ocean dynamics.

Facilities provided under this contract form an integral component of a tripartite observing system. They consist of an appropriate selection of hardware and software capable of reducing both satellite and in situ data, integrating the data into a four dimensional display of the recovered fields, and providing a convenient and powerful interactive tool for the joint analyses of these data.

Our approach involves selecting a relatively low cost, general purpose, image processing and computational system which provides the greatest flexibility for the individual researcher, for integration of software developed at other institutions, as well as for future growth. Specialized software will be created for specific oceanographic experiments in which these facilities will be used for analysis of both in situ and remote sensing data.

This project was initiated in September 1982. At this writing we have selected and begun procurement of the hardware/software system (the ESL, Inc. VAX/IDIMS) which will be implemented in late spring 1983 and have appointed to the Technical Staff a specialist in image and digital signal processing, Mr. Kelly Luetkemeyer. A preliminary investigation of applicable software resident at other institutions has been conducted. An initial set of six field experiments has been selected to test the system beginning in 1983.

This work is jointly sponsored by the Office of Naval Research and the National Aeronautics and Space Administration.

# LARGE SCALE WIND-DRIVEN OCEAN CIRCULATION

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Long-Term Interests: To incorporate satellite measured winds and sea surface elevation in statistical and numerical studies of the large scale, low frequency dynamics of wind-driven ocean circulation.

Specific Objectives: There are two primary objectives of the present work. The first is to evaluate the scientific usefulness of the satellite wind and sea surface elevation estimates from the Seasat instruments. The second objective is to examine upper ocean response to wind forcing from the Seasat data and existing historical data.

Approach: The approach for determining the usefulness of satellite wind estimates consists of carrying out a statistical intercomparison of the three satellite wind speed measurements with each other and with available in situ measurements. The approach of the second objective is to form linear statistical predictors of the sea surface dynamic topography and relative geostrophic velocity using wind stress and wind stress curl as forcing parameters. This part of the study is focusing on the variability in the California Current and Antarctic Circumpolar Current regions. The wind data presently used consists of the quasi-geostrophic wind fields produced by FNOC from ship reports of atmospheric pressure.

Current Status: Studies of low frequency surface current response to wind forcing off the west coast of North America from historical data were completed during FY'82. During FY'83, these studies of surface current response are being extended to investigate the relation between subsurface currents (i.e., the undercurrent) and wind forcing off California.

Analysis of Seasat data during FY'82 showed that SASS, ALT and SMMR can all measure wind speed over the ocean with sufficient accuracy for studies over monthly time scales. Differences in wind speed magnitudes by the various methods can be attributed to errors in the algorithms for converting the antenna measurements to wind speed. Efforts to determine the exact causes and corrections for these errors will be continued during FY'83.

A new study to be initiated during FY'83 is the examination of variations in the flow of the Antarctic Circumpolar Current from Seasat ALT sea surface elevation. An attempt will be made to relate variations in the flow to wind forcing using SASS wind estimates.

# OCEAN CIRCULATION STUDIES USING SEASAT ALTIMETER PROFILES

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Long Term Interests: Satellite altimeters are unique in their ability to rapidly obtain precise measurements of sea surface height on a global basis. Proper analysis of these data can reveal important information about ocean circulation. Existing data from Seasat and GEOS-3 provide a basis for technique development and investigation of altimetric capabilities.

Specific Investigation Objectives: The principal goals of altimetry are to determine both the long term mean ocean circulation and its variability. Recent emphasis has been on the use of geoid-independent models to solve for mesoscale sea height variability. Meandering currents can be detected in this manner and the eddy field can be described in terms of dominant length scale, period, potential energy, and kinetic energy. Improvements in orbit computation techniques and global geoid models have also raised the possibility of determining the large scale ocean circulation using existing altimeter data.

Approach: Mesoscale sea height variability and eddy kinetic energy can be measured globally with the 25-day set of Seasat altimetry. Long term solutions can also be obtained in certain regions such as the western North Atlantic using the 3.5 year set of GEOS-3 data. Both collinear pairs of passes and crossover differences can be used to describe the mesoscale eddy energy. The global circulation can be determined from altimeter data sets as short as three days or as long as three years. The pricipal error source to overcome is orbit error, which can be of order 1 m.

Status: Global variability determined from the Seasat collinear data has clearly shown that the major current systems are regions of high eddy energy. Even the North Equatorial Currents have been detected as maxima against the background of low variability provided by the eastern regions of the oceans. Long term variability and eddy kinetic energy computed in the western North Atlantic from GEOS-3 data have been shown to be more representative of the eddy energy distribution than previou determinations by shipboard XBT data. Global circulation solution derived from both Seasat and GEOS-3 altimeter data have succeeded in reproducing the major gyres with the proper direction of flow.

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# LIDAR AND ACOUSTICS APPLICATIONS TO OCEAN PRODUCTIVITY

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Long Term Interests: The long term goals of this program are to understand the relationships between the physics and the biology of the upper mixed layer. To achieve this goal, it is important to understand the relationships between phytoplankton productivity and the vertical and horizontal variability of the ocean on spatial and temporal scales which are large compared to the scales of the biology. Included in the study are the relationship between chlorophyll abundances and phytoplankton productivity, the productivity of zooplankton in the upper mixed layer and the dynamic interactions between phytoplankton and zooplankton.

Objectives: The objective of this research is to develop in situ instrumentation capable of examining the three-dimensional structure of the ecological systems involved in ocean productivity. The emphasis is on optical and acoustical techniques that will permit remote observation from in situ platforms.

Approach: The approach is to develop an in situ LIDAR instrument capable of the range-gated measurement of the vertical distribution of fluorescence and spectral reflectance from chlorophyll and other pigments. This unit will use the water Raman return as a measure of the optical properties of the water column, and will use Raman and Brillouin scattering for the remote measurement of temperature and salinity. In addition, the development of a linearly frequency modulated sonar will permit the range-gated measurment of the vertical distribution of zooplankton species in the euphotic zone.

Status: A collaborative effort with Dr. D. Kiefer and Dr. J. SooHoo to examine spectral signatures from phytoplankton and certain aspects of phytoplankton physiology is in progress. These measurements will be used to develop algorithms to determine the chlorophyll concentrations and to study the physiology of the phytoplankton population. Laboratory measurements have demonstrated the accuracy of the Brillouin temperature measurement and are proceeding to a definition of the accuracy of the Raman technique. An acoustic instrument has been constructed in collaboration with Dr. R. Pieper and is being tested to compare the chirp and ping sonar techniques for the measurement of zooplankton size class distributions.

## ADVANCED LOCATION AND DATA COLLECTION SYSTEM

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TASK 01 - Advanced System Study

Objective: The long term objective of this activity is to develop an advanced system which meets requirements for low-cost platforms and possesses sufficient capacity to meet ocean requirements projected for the next decade.

Approach: Our approach is to complete system design studies incorporating anticipated growth capability to meet future needs. Trends and needs are defined through consultation with the ocean research community.

Current Status/Progress: A system concept and instrument performence specification for an advanced system have been completed. The concept is based on location through interferometry and combines a high and low data rate into a single system. In addition, features such as improved modulation spectral qualities were synthesized into the Argos system, and improved performance was estimated. To summarize the above, the improved system increases platform capacity from 200 to 600 simultaneously in the field of view, relaxes critical platform parameters such as oscillator stability, increases data throughput capacity to 20 KB/sec, and provides uniform location accuracy over the total field of view, including the subtrack region. A small study is also underway to consider advantages in location and data throughput attained by future capabilities of space station configurations. This study will be completed in early 1983.

# ADVANCED LOCATION AND DATA COLLECTION SYSTEM

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## TASK 02 - Existing Systems Improvement

Objective: The objective of this activity is to imprve existing systems by reducing cost and complexity of buoy electronics. This in turn permits expanded usage to include ocean experiments using in-situ techniques.

Approach: In support of short and long term drifter experiments, techniques to reduce stringent specifications for carrier stability will be studied and tested with the Argos system. Low-cost buoy oscillator developments will permit near term applicayions with Argos while supporting future goals.

Current Status/Progress: Two activities were carried in conjunction with improvements in the Argos system: 1) low-cost oscillator testing, and 2) system simulation to improve data throughput of existing systems. Tests of commercial grade low-cost oscillators have been very encouraging. Results indicate that the ocean environment is sufficiently stable to permit the use of devices with stability in the range of one part $10^6$ to match performance of oven-controlled compensating devices. Efforts are continuing on improvements of the statistical measurements base while also determining an absolute minimum device capable of meeting performance requirements.

We conducted a system simulation based on high data volume buoys interspersed with drifters within the Argos system. Results indicated that by extending the collection period from one to four orbits, up to 80% of data transmitted from high volume buoys could be received at a reasonable bit error probability. It appears that this can be done without affecting the system operation now in effect.

Efforts are underway to design and procure a limited quantity of Argos platforms using relaxed specifications permitted by the above. Field and laboratory testing is planned to fully evaluate performance. Cooperative efforts with Woods Hole and Scripps are planned during this phase.

## BATHYMETRIC PREDICTION AND TOPOGRAPHIC COMPENSATION FROM SEASAT ALTIMETRY

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This investigation is directed at understanding the regional variation of certain geologic properties of oceanic crust and upper mantle, and corresponding variation in the geoid. Since a major component of the signal in satellite altimetry is caused by sea floor bathymetry and sub-surface structure in the crust and upper mantle, an accurate understanding of these effects is necessary before altimetry can be used to full potential for oceanographic purposes. An accurate geoid cannot be estimated solely from a priori knowledge of bathymetry due to uncertainties in the compensation mechanism and other geophysical parameters. Even knowledge of the relative ages of seafloor and topography may not be sufficient constraints.

The first 18 months of this study have concentrated on various aspects of bathymetric prediction and geophysical modelling in the Musician Seamounts. Results of this study have been accepted for publication. Assuming an age estimate for topography is available, bathymetry can be estimated from the altimeter data to a precision of about ± 500 m. Conversely, if bathymetry is known, a crude age estimate for topography (e.g. seamount formation) can be made. A predictive filter for bathymetry has been developed which uses Seasat altimeter data and age estimates of the topography and underlying crust as inputs.

The major uncertainty in bathymetric prediction, or the more general problem of modelling topographic compensation, stems from the one-dimensional nature of the Seasat data. Intertrack data spacing is comparable to the characteristic wavelengths of bathymetric and crustal variation only in the Norwegian-Greenland Sea. Initial work has begun on investigating the general two-dimensional problem of correlating sea surface elevation with seafloor topography and sub-surface structure. Although the techniques of linear inverse theory are applicable, they have not as yet been applied to altimeter data. We have therefore concentrated on technique development. The relationship between seafloor and sea surface elevation can be expressed as a Fredholm equation of the first kind in the linear approximation. To reduce the amount of data, the singular value decomposition operation replaces the original data set with a set composed of "orthogonal" values which can be reliability-weighted. This results in a sophisiticated "grid" of data that accurately represents the original information, but with a much smaller number of data points.

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# A FEASIBILITY STUDY OF THE DEVELOPMENT OF A MOORED FLUOROMETER TO SIMULTANEOUSLY ESTIMATE PRIMARY PRODUCTIVITY AND CHLOROPHYLL IN AQUATIC SYSTEMS

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The primary long term objectives of this research effort are to develop a quantitative understanding of the processes regulating primary production and the distribution of primary producers on continental shelves. To help achieve this understanding, we have developed moored fluorometers with low power consumption which will be placed across the continental shelf in a "T" arrangement in 1984, 1986, and 1988 as part of a Department of Energy program.

This research effort is directed towards developing a multiple flash fluorometer where the ratio of fluorescence yields between two or more closely spaced flashes provides an estimate of photosynthetic rates. If the basic ideas are verified by experiment, a shipboard, and subsequently a moored, intrument could be constructed to remotely detect photosynthesis.

The approach is based upon models relating photosynthesis to fluorescence in vivo, which have been developed since 1963. It is proposed that the fluorescence yield between two closely spaced flashes (30 $\mu$sec peak-to-peak) will provide quantitative information about the flux of electrons which have passed through the primary electron acceptor of photosystem II.

Funding for this program began 1 October 1982. Necessary equipment has been purchased and laboratory experiments have been initiated.

# WAVENUMBER SPECTRUM OF OCEANIC MESOSCALE VARIABILITY FROM SATELLITE ALTIMETRY

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Long-Term Interests: My long-term interests in satellite altimetry are its applications to the studies of the mesoscale variability and general circulation of the oceans. The dense and global coverage of a multi-year altimeter mission will eventually allow us to make a complete description of the oceanic variability in both frequency and wavenumber domain. Before the advent of such a mission, I am interested in exploring the full utility of satellite altimetry to these problems by studying the existing data from the Seasat and Geos-3 altimeters.

Specific Objectives: The objective of this research task is to use the Seasat altimeter data from nearly repeat tracks to compute the wavenumber spectrum of oceanic mesoscale variability in various parts of the oceans. The emphasis is placed on the exploration of the spectral differences between areas of high eddy energy and areas of low eddy energy.

Approach: The approach taken is to compute a mean sea-surface height for each group of repeat tracks. Then this group mean is subtracted from each individual track and the residuals are subject to spectral analysis. Affects of the contamination from residual geoid due to finite track separations and range delay due to atmospheric water vapor are also examined.

Current Status: This task has been completed, and the results are described in a manuscript which is now under review. The major results of the study are the findings of two considerably different spectra depending on the eddy energy level. In the high-energy areas, most of the energy is contained at wavelengths longer than 250 km; at shorter wavelengths, the spectrum follows a $k^{-5}$ (k is wavenumber) dependence. In the low-energy areas, the spectrum follows a $k^{-1}$ dependence at wavelengths from 100 to 1000 km. The results of the residual geoid study proved useful for specifying the accuracy requirement for the Topex repeat orbits.

## SAR STUDIES OF OCEAN SURFACE AND INTERNAL WAVES

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Long-Term Interests: As demonstrated by Fu and Holt (1982 a, b), a spaceborne synthetic-aperture radar (SAR) has the ability to provide a high-resolution (~25m) view of a wide range of oceanic phenomena. Because of its high resolution and all-weather capabilities, the utility of SAR for observing small-scale, highly transient phenomena like surface and internal waves is unique. One of my long-term research interests is the application of SAR data to ocean surface and internal wave studies.

Specific Objectives: The objectives of this research task are (1) to analyze the surface wave field generated by extratropical storms using a combination of data from the SAR, altimeter, and scatterometer on Seasat, and compare the results with those of wave hindcast models, and (2) to study the internal waves in the Gulf of California using the Seasat SAR images, which have extensive repeat coverage of this area.

Approach: The approach taken for the surface wave study is to make a synoptic description of the waves generated by a severe storm in the North Atlantic, using wave heights from altimeter, winds from scatterometer, and directional wave spectra from SAR. The results are compared with the FNOC hindcast forced by winds from a conventional source. I have also sought collaboration with Willard Pierson of CUNY to attempt at studying the impact of using scatterometer winds in the wave hindcast. The approach taken for the internal wave study is to analyze repeat images, from which the processes of wave generation, propagation, and dissipation can be studied.

Current Status: Preliminary results from the surface wave study show an overall agreement between the data and the model, with the discrepancies attributable to the errors of the wind field used by the model. Preliminary results from the internal wave study suggest that the energetic internal waves in the Gulf of California are forced by the $M_2$ tide, and that the dissipation of these waves accounts for a modest fraction of tidal dissipation in the Gulf. Both studies are expected to be completed by the end of FY'83.

# AN INVESTIGATION OF THE UTILITY OF OCEAN COLOR IMAGERY FOR DELINEATION OF OCEANIC PROCESSES IN THE WESTERN NORTH ATLANTIC

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Long Term Interest: To understand the color of the ocean and its variability in space and time as observed by the Coastal Zone Color Scanner (CZCS), in relation to physical and biological processes.

Specific Research Objectives: (a) To compare horizontal flow fields based on the observed differences in the position of identifiable features in CZCS imagery Obtained on successive days (as is done for cloud motion vectors in the lower atmosphere) with current measurements; (b) to compare the CZCS thermal and color imagery; and (c) to study the long term stbility of the CZCS algorithms.

Approach: The area chosen to carry out the study is the Middle Atlantic Bight, a region of intense study in 1982 by the Warm Core Rings (WCR) Project. WCR investigations will yield the ancillary surface data (surface current, pigments, and thermal structure, etc.) needed for comparison with CZCS imagery. Currents will be qualitatively and quantitatively compared to CZCS-derived flow fields, and ship-measured pigments will be compared directly with their CZCS-derived counterpart. Comparison of the horizontal variability observed in thermal and color imagery will be made through the use of two-dimensional power spectra, computed for sub-scenes of various sizes.

Status: Software for the generation of flow fields from color and thermal imagery acquired on successive days have been developed and installed at the RSMAS Image Processing Facility. Algorithms for the computation of two-dimensional power spectra of large data sets (1000x1000 pixels) are also in place at the facility. CZCS and NOAA-7 station tapes have been obtained for the four WCR field experiments, and these have all been converted to computer compatible tape format for further processing. Ancillary surface data acquired during the experiments are presently being reduced by the individual investigators. Analysis of early CZCS imagery is being used to better determine the long term sensor drift.

# MICROWAVE EMISSION FROM POLAR SURFACES

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Long Term Interests: Our interests are the intermediate and large scale effects of sea ice on the interaction between the ocean and atmosphere, and the influence of the polar regions on global climate. The large scale energy exchange is governed by the ice thickness distribution and is very sensitive to the fractional area covered by thin ice and open water where exchange rates can be as much as two orders of magnitude larger than over thick ice. We want to determine the extent to which passive microwave data from satellite-borne sensors can be used to study ice concentration and ice type distribution on scales of $10^4$ $km^2$ and above.

Objectives: Our present objective is to see how well multifrequency passive microwave observations can distinguish among arctic sea ice types at different times of year with special emphasis on the period from the beginning of the summer melt through fall freezup. Through a series of surface based measurements (in conjunction with aircraft and satellite overflights carried out by other investigators) we expect to be able to provide accurate ground truth data for calibration and interpretation of the remote observations. We also want to understand how the physical characteristics of the ice influence the microwave emission.

Approach: Surface based measurements of microwave signatures for the ice types in a particular region are staged from field camps, and the instruments are transported to the sites by hand drawn sled or by helicopter. Brightness temperatures are obtained in H and V polarizations at 10, 18, and 37 GHz. At each site small scale spatial variations are obtained over a 100 to 300 m track together with the dependence of brightness temperature on angle of incidence at several interesting locations. Surface temperature, salinity, near surface grain size and structure, and a qualitative estimate of free water distribution are also made along the track.

Current Status: During the past year we have acquired and tested a set of three microwave radiometers (10.7, 18.7, and 37 GHz). We have carried out field studies in the Chukchi Sea, in the Cascade Mountains of Washington, and in the southern Beaufort Sea, near Tuktoyaktuk, NWT. The observations at Tuk included measurements of microwave emission from cold snow and thick first-year ice together with the physical structure of these surface types. At Mould Bay we studied thick first- and multiyear ice from mid-June to mid-July. We have also been developing a radiative transfer model to attempt to predict brightness temperatures of sea ice from the physical and thermal structure data. We have contributed to the planning of and intend to participate in both the MIZEX East and West efforts during the next few years.

# A NOVEL ALGORITHM FOR SEA SURFACE HEIGHT ESTIMATION USING COMPLEX SAR DATA

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The objective of this research is to study the fundamental SAR system model and the sea surface height estimation algorithm. We wish to understand the nature of the fundamental SAR system model for oceanographic application in order to predict SAR imagery - ultimately to be used in applications such as current measurement and bathymetry. Secondly, we wish to determine the applicability, accuracy, and system design implications for the height estimation algorithm; the study will emphasize numerical simulation and calculation and the use of actual SAR "complex" data.

Specifically, we intend to study a novel, nonlinear algorithm used to process SAR complex imagery to extract large scale sea surface height as a function of position - i.e., the sample function itself. An initial processing algorithm was simulated and applied to the available Seasat SAR complex imagery, and the results were viewed as very encouraging.

Present efforts are directed at the following: 1) finding improved (nonlinear, minimum error variance) recursive estimators of the large scale structure based on random and/or chaotic dynamical models (soon to be completed), 2) simulating the sensing mechanisms and processing algorithms to determine performance - e.g., accuracy and robustness, and 3) analyzing SAR complex imagery gathered in the JASIN project.

# OCEAN MODELING AND DATA ANALYSIS STUDIES

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Long-term interests center around understanding the physical processes that are important in the low frequency ocean general circulation, in learning how to model the ocean on these scales and in using ocean models to investigate the role(s) of the ocean in the earth climate system. This requires knowledge of the air-sea interaction processes which produce the surface heat, salt, mass and momentum fluxes that drive the ocean and also how to parameterize the effects of ocean "turbulence" on the flow scales of interest

Specific investigation objectives are of two types. The first involves the development and use of numerical ocean models with various degrees of physical sophistication, in order to study the effects of different ocean processes in sufficiently idealized circumstances to make their effects understandable. The second involves data analysis projects directed at determining how well the ocean wind stress and sea surface temperature fields are known on different space and time scales from conventional and satellite observations. These fields are needed for various modeling studies and also establish the standards that satellite observing systems should meet for maximum utility.

Modeling results on the circulation of the subtropical and subpolar gyres have been obtained, using a very simple barotropic vorticity equation model. These results emphasize the critical importance of vorticity transport, either by the mean western boundary current systems (the model "Gulf Stream" system) or by eddy processes across the "Gulf Stream" front, in establishing the dominant qualitative flow behavior of the system. Further, they illuminate why conventional coarse resolution ocean models do not satisfactorily reproduce many important features of the observed ocean circulation. Further studies, to investigate the effects of different subgrid-scale "turbulent closures" on the flow patterns, are being carried out. Another study has examined the differences between a "quasi-stationary" solution to a quasigeostrophic ocean model and the conventional time-averaged solution to the same model. The changes induced by mesoscale eddies on the ocean circulation are now being examined. A tropical modeling study on the thermal changes induced by downwelling Kelvin wave passage (forced by wind changes) shows that the changes result from anomalous advection and are very sensitive to the state of the ocean when the Kelvin wave arrives. Under some conditions, temperature changes very like those of the initial stage of El Niño are obtained.

Evaluation of the climatological air and surface temperature, wind and wind stress fields for the world ocean is now complete and analysis of this data is underway. These results are being prepared for a high spatial resolution climatology for the world ocean. Anomaly studies are also underway. The first detailed comparison of monthly mean surface wind fields (tropical Pacific, Nov. 1979) from seven different sources has been made and is being prepared for publication.

This work continues to be done in close contact with scientists and staff of the Goddard Laboratory for Atmospheric Sciences. Other support is received from the National Science Foundation and the National Oceanic and Atmospheric Administration.

# CALIBRATION PROCEDURES AND STANDARDS FOR ACTIVE MICROWAVE REMOTE SENSORS

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## Long Term Objectives

Spaceborne missions for the remote sensing of earth resources and oceanic processes which will fly in the late 1980's will probably include Synthetic Aperture Radars (SAR) as well as other active microwave sensors. For many appplications it is essential that these sensors be radiometrically calibrated to facilitate the accurate interpretation and intercomparison of the resultant data.

## Specific Task Objectives

The objective of this task is to develop and test techniques and standards applicable to the calibration of Synthetic Aperture Radars, and in addition, to develop the techniques and standards necessary for the cross-calibration of SAR imagery with other active microwave sensor data.

## Approach

Over the three year period scheduled for this task we will: 1) conduct a thorough literature search; 2) analyze and simulate the effects of system nonlinearities; 3) develop specific techniques and standards for calibrating SARs; 4) aid in the design and implementation of the aforementioned techniques on the JPL CV990 radar; 5) evaluate any pertinent SEASAT SAR data.

## Current Status

A systematic procedure has been developed for calibration of SEASAT SAR data. This procedure does the following: 1) Identifies data which cannot be calibrated due to extreme system nonlinearities such as receiver saturation or missing data lines; 2) Corrects for variations in the SEASAT-Earth analog data link gain using a reference pilot tone included in the data; 3) Compensates for image brightness errors resulting from imaging geometry and antenna pattern effects; 4) Finally obtains absolute cross section estimates based upon thermal noise levels measured with the SEASAT transmitter turned off. Another estimate is obtained using the calibrated pilot tone level.

These methods are currently being refined to take into account all of the parameters pertaining to digital SAR processing. Preliminary data from this procedure has been compared to Scatterometer tracks on several test scenes with encouraging results. This year we plan to cross calibrate with SAR data obtained from CV990 Aircraft Radar.

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# NUMERICAL MODELING OF SEA ICE DYNAMICS AND ICE THICKNESS CHARACTERISTICS

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This research effort is motivated by a long-term interest in air/sea interaction in the presence of an ice cover. Of particular interest is the nature of sea ice dynamics and the role it plays in air-sea interaction and, more generally, in climatic change.

The overall objective of this program is the development and verification of numerical models for simulating the large-scale dynamics and thermodynamics of sea ice. Particular emphasis has been placed on developing ice dynamics parameterizations for use in seasonal sea ice models relevant to climatic studies. A secondary objective is to examine smaller-scale ice dynamics problems relevant to the Marginal Ice Zone.

The approach in this work is to combine parameterizations of various physical processes to form a model. The model is then examined numerically to determine its agreement with observations and to identify the role of different processes in the model results. Work this year has been split between seasonal equilibrium simulations of the Antarctic Sea pack ice and small-scale (18.5-km resolution) idealized simulations.

For a first test of an Antarctic sea ice model, the two-level dynamic thermodynamic sea ice model developed by Hibler (1979) was extended to include ice edge characteristics and was applied to the Weddell Sea ice pack. The simulations use a one-day time step on an 18x15 grid with a resolution of 222 km. Daily atmospheric data from 1979 together with empirical radiation fields drive the simulations. With atmospheric temperature fields modified to reflect buoy observations, the simulations yield a seasonal cycle of ice with maximum and minimum extents close to that observed. Except for portions of the western Weddell, the advance of the ice is found to be primarily thermodynamic in nature, while the rapid decay depends critically on the presence of both leads and lateral ice advection. The average fraction of open water is substantial even in winter, and varies from a minimum of 10% in September to a maximum of 35% in March. In early summer the ice motion causes a residual tongue of ice to extend eastward from the Antarctic Peninsula in agreement with observations. Mean ice thicknesses are consistent with observations and vary from about 3 m in the perennial ice in the western Weddell to 1 m in first-year ice in the eastern Weddell. Simulated ice drift results yield mean drift rates of about 5 km/day, in good agreement with buoy drift observations. Simulations were also carried out with a simple feedback assumed between the ice extent and atmospheric temperatures. These ''coupled'' simulations yield a more realistic rapid decay in summer witn dynamics included, but an unrealistically small decay without dynamics. Two journal articles describing this work have been accepted for publication.

With respect to small-scale dynamics, idealized build-up simulations showed that with a plastic interaction it is possible for certain locations to have fluctuating velocities, even though the wind forcing is fixed. To yield insights into these results a one-dimensional rigid plastic model was solved analytically, with the results being consistent with the numerical simulations.

In addition to support by NASA, the Antarctic work was jointly supported by NSF, and the small-scale work by the Swedish Meteorological and Hydrological Institute.

# APPLICATIONS OF LASER TECHNOLOGY

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Long Term Interests: To demonstrate that existing airborne laser technology and electronic systems can provide valuable, synoptic, quantitative physical and chemical oceanographic data. As such, these systems can enhance the scientific understanding of the ocean surface as well as the subsurface water column. My interests also include improving calibration of satellite color scanners and altimeters.

Specific Objectives, Approach, and Progress: A. Biological and Chemical Oceanography. My objective in this area of research is to demonstrate an accurate method of measuring chlorophyll a and other phytoplanktonic photopigment concentrations using integrated laser induced fluorescence (LIF) at 685 nm with a calibrated airborne laser fluorosensor. Warm Core Ring (WCR) Experiment data have been obtained during four separate overflights of WCR 82-B. Ongoing analysis is aimed at the quantification of results from these missions, and the production of synoptic contour plots of fluorescence data. Water Raman backscatter, as well as PRT-5 and AXBT temperature data recorded simultaneously with the fluorescence data will also be utilized. Comparing airborne laser chlorophyll a measurements with shipboard and CZCS data is considered high priority for understanding phytoplankton dynamics and ultimately primary productivity. Previous agreement of airborne chlorophyll a measurements with shipboard observations has been good. The goals of this task will be achieved through corroboration with participating scientists in the WCR Experiment. A secondary objective is to demonstrate an accurate method for the measurement of organic matter using integrated LIF in the blue-yellow spectral region with the airborne laser fluorosensor. B. Physical Oceanography. My objective in this area of research is to demonstrate the remote measurement of water column optical attenuation using laser-induced water Raman and Mie backscatter decay as a function of depth. Better quality airborne Raman bathymetry data, complete with diffuse attenuation sea truth, as well as improved deconvoluted algorithms, are needed to remove lidar system response time. Depth resolved Raman backscatter data have now been obtained at 380, 493.5, and 650 nm from stimulation by airborne lasers operating at 337, 422.6, and 532 nm. Recent Monte Carlo modelling techniques have helped to better define the processes and properties governing the lidar backscattering and attenuation in the water column. A secondary objective in the physical oceanography area is to evaluate the distribution of power relative to sea surface elevation under varying wind and wave conditions. These observations are essential to develop an understanding of water surface scattering and reflectance properties due to the distribution of small scale wave structures. The observations are also important for achieving a fundamental understanding of the effects of the water surface on lidar measurements made within the water column.

# MICROSCALE OCEAN SURFACE DYNAMICS

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Long Term Interests: Air-sea interaction processes control the flux of momentum, energy, mass, and heat from air to water and vice versa; therefore, any changes in the air or water will be reflected in corresponding changes of the surface microscale structures in the form of wind waves. Consequently, the study of microscale ocean surface dynamics will increase our understanding of air-sea interaction processes, and will also provide us with the foundation for proper interpretation of microwave remote sensing data.

Specific Objectives: (1) To study the detailed statistical characteristics of the ocean surface, (2) to study the spatial and temporal relationship of the wind waves, and (3) to study the evolution of wind waves and their relationship to the turbulence intensity of the surface layer. The approach adopted here is to conduct a selected number of carefully controlled experiments at the wind-wave-current interaction facility at Wallops Flight Facility (WFF), and to check these results in the field. Theoretical analyses will be emphasized at the same time. Our aim is to understand the basic physics of the processes. Therefore, our approach is analytical and physical rather than empirical. This study is cnducted as a joint effort between NASA/WFF and Profs. O.M. Phillips and S.A. Kitaigorodskii of the Johns Hopkins University, Prof. E. Mollo-Christensen of MIT, Prof. C.C. Tung of the North Carolina State University, and scientists at the Naval Research Laboratory.

Progress: All the studies are in progress. Major findings are summarized below. (1) From theoretical studies, we established a new nonlinear mapping method to produce a non-Gaussian statistical model of the ocean surface wave field. This model is an improvement over the Gram-Charlier expansion used previously. (2) From theoretical and experimental studies, we established the mechanism for determining the electromagnetic bias for the radar altimeter both in significant wave height and the mean sea level measurements. (3) Jointly with MIT, we constructed and tested a harp probe for in-situ study of the Bragg scattering mechanism. From the laboratory test, it was found that the harp probe exhibited resonance with the waves satisfying the Bragg condition. The results further established that most of the waves are freely propagating under light wind stress. Other applications are under study.

Partial support for the study comes from the Naval Research Laboratory.

# MICROWAVE RADAR OCEANOGRAPHIC INVESTIGATIONS

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Long term interests are in the remote sensing of ocean surface waves and surface conditions, electromagnetic interactions, wave dynamics and upper ocean dynamics.

Specific objectives of this task focus on the end objective, which is the development of a spaceborne microwave radar capability for global measurements of ocean wave directional spectra. Toward this end we have been conducting a program of theoretical and experimental research involving the application of real-aperture, short-pulse radars, essentially as an alternative approach to coherent imaging radar. Our research to date has shown that rather accurate measurements of the directional energy spectrum are possible at satellite altitudes simply by modifying existing satellite altimeters so as to include an off-nadir conical scan mode (nominally 10° incidence). Specific objectives for the current year include a) Obtaining additional aircraft verification/intercomparison data, especially for directionality, using the Wallops Surface Contour Radar (SCR), b) At the same time, conducting useful science experiments with the GSFC Ku-band radar--for example, fetch-limited wave growth measurements, and c) Defining a Space Shuttle experiment to demonstrate the short-pulse radar ocean wave spectrometer (ROWS) technique.

Current status. This is the third year of funded activity. The theoretical work, including the specular scatter solution and short pulse/dual frequency tradeoff analysis has been completed and published in Radio Science (Vol. 16, pp. 1385-1400). The validation phase of the Fall '78 Mission data analysis is complete, and the results are to be published in the (refereed) Proceedings of the Miami Symposium on Wave Dynamics and Radio Probing of the Ocean Surface. The remainder of the Fall '78 data set has been processed, and we have begun a case study using this data to evaluate the performance of numerical wave models in storm sea conditions. The GSFC radar is presently integrated on the Wallops P-3 aircraft, and we have conducted four flights with E. Walsh's SCR (Hurricane Debby and three fetch-limited cases). With the new antenna configuration on the P-3, we shall now be able to measure the mean square slope parameters and principal axis orientation; this will permit the proper estimation of the modulation spectrum/slope spectrum sensitivity coefficient and allow a determination of the large-wave contribution to the near-nadir cross-section. Jointly with code 970, we are initiating a Shuttle experiment definition study for an integral Altimeter/ROWS instrument based on available space hardware.

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# OCEAN WAVE HEIGHT DETERMINATION WITH SAR

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Long Term Interests: Our long term interest is to develop radar instrument concepts that will provide a capability for quantitatively monitoring ocean surface phenomena from space.

Specific Objectives: The specific objective of this research task is to develop and demonstrate techniques to measure ocean wave spectra with the Synthetic Aperture Radar (SAR) utilizing SEASAT data. Two techniques are being investigated: 1) obtaining SAR images utilizing small sections of the total signal bandwidth, determining the normalized average intensity of pairs of such images as a function of frequency separation, and determining the properties of this curve; and 2) obtaining the spectra of the SAR images. Theoretical work combined with data analysis is being conducted on both these techniques.

Approach: SAR data from previous JPL flights have been used for concept verification of the wave height measurement technique. These include data obtained from SEASAT. Surface truth is available for this data set and is being compared for wave height measurements obtained by the radar. Results have shown good correlation. Continuing work is focused on developing an understanding of the physical relationships between ocean surface processes and these techniques.

Comments: Continuing measurement of ocean wave height with the SAR has been demonstrated on the SEASAT data base. Work to extend the measurement to wave spectra is in progress.

# REMOTE SENSING OF OCEANIC CURRENTS

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Long-term Interests: My long term interests are the study of coastal surface currents and their relationships to wave fields, wind stress, mesoscale phenomena, sub-surface currents and bottom topography. I am also interested in developing applications for a high resolution surface current measuring system, the Coastal Ocean Dynamics Application Radar (CODAR), and in promoting CODAR as an everyday oceanographic tool for direct measurement and as ground truth (e.g., for SAR and SLAR).

Specific Objective: The Coastal Ocean Dynamics Experiment (CODE) provides an opportunity to make surface current measurements in an area of relatively simple bottom topography and large wind stress events. With complementary data sets of wave fields, wind, hydrography, subsurface currents, and bottom stress, the relevant physical parameters needed to construct accurate kinematic and dynamic descriptions of the response of shelf-water to strong wind forcings can be thoroughly examined. SAR and SLAR data sets from CODE will be used to access CODAR as an instrument for the evaluation of these observation techniques.

Approach: CODAR is a high-frequency, ground-wave mode, radar that measures the Doppler shift of the sea echo from which one can calculate high-resolution, accurate, surface currents for a coastal area on the order of $10^3$ km. With a sufficiently long time series, CODAR measurements can be used to identify and separate tidally-driven from wind-driven currents, and to define the temporal and spatial scales of the response of surface waters to strong wind forcing.

Status: During CODE-2, CODAR measurements were taken for 30 days at an interval of 15 minutues. The data quality is excellent, there was little interference in our area, and there were no hardware failures. We are repacking the data into intervals of one hour; from the hourly time series, we can calculate tidal coefficients and quickly identify any periods of significant wind events for detailed examination. The software also exists to treat CODAR data in an Eularian manner for complementary studies with moored and airborne instrumentation, or in a Langrangian manner for complementary studies with drifter instruments.

# STORM TRANSFER AND RESPONSE EXPERIMENT (STREX) MICROWAVE BACKSCATTER/WIND STRESS INVESTIGATION

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The purpose of this experiment was to study the relationship between ocean radar backscatter and the vector wind stress. During STREX, four flights were conducted where simultaneous radar and wind stress data were obtained on board two aircraft flying in a vertically stacked formation.

During 1982 radar scatterometer data analysis was conducted under a NASA grant with Univ. of Mass. and in cooperation with NASA LaRC. Wind stress data analysis was provided by the Univ. of Wash. For the turbulent comparisons, simultaneous series of radar backscatter and wind stress were correlated for the various low altitude lines of the P-3 and/or Electra. To enhance the correlations, the INS winds were converted to a pseudo-NRCS using results from the Seasat-A Satellite Scatterometer (Schroeder, et al., 1982). With this approach, winds were raised to a power (approximately two) determined from the SASS Model Function for the corresponding incidence angle and relative azimuth (between the radar look angle and the wind direction). Next the series were normalized and detrended prior to performing the cross correlation process.

Coregistered NRCS and INS wind speed spatial series were Fourier analyzed to compare the spectral content in these independent data. The long wavelength portion of the wind and radar spectra are highly correlated and track one another in both amplitude and dominant frequency. This observation implies that the time constant for the capillary wave spectrum to respond to changes in the surface winds is very short (of order seconds).

The initial objectives of this STREX experiment have been satisfied in that AMSCAT data have been processed to absolute NRCS and delivered to the STREX project.

Preliminary spectral analysis have been performed which indicate that there is strong "real-time" correlation between the long wavelength components of the wind and the small scale ocean roughness (capillary waves) which produces radar backscatter. At shorter wavelengths, the measured INS winds and the NRCS decorrelate probably due to imperfect coregistration (estimated to be greater than + 1 km).

The analysis performed thus far should be considered preliminary, but good progress is being made toward final results. Plans are being made to publish results in a special "STREX" issue of Journal of Geophysical Research in 1983.

# ACOUSTIC PROFILING OF UPPER OCEAN CURRENTS

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Oceanic fronts occupy scales smaller than synoptic scale eddies, yet are often associated with these disturbances when water mass contrasts are present. Mechanisms by which these fronts are formed and are dissipated are among the long-term interests of the principle investigator. The ability to survey upper ocean currents greatly improves the chances to gain new insight into the dynamics of upper ocean fronts.

The objective of this research task is to be able to routinely and accurately measure upper ocean currents from a ship using acoustic doppler techniques. The principle field activity for FY82 consisted of five cruises aboard the R/V ENDEAVOR associated with the National Science Foundation study of Warm Core Gulf Stream Rings. A preliminary cruise in May, 1981, was supported by NASA. During this short cruise, the R/V OCEANUS performed doppler current and XBT surveys near Nantucket Shoals, in support of an on-going NASA experiment in the area, in a Warm Core Ring, and across the Gulf Stream south into the Sargasso Sea. A data report from this cruise is now being published. Data from the five ENDEAVOR cruises are now being analyzed.

One of the results from our OCEANUS report was an intercomparison of our acoustic doppler shipboard current profiler with a moored vector-measuring current meter. Hourly averaged currents were compared over a four-hour period while OCEANUS was keeping station two nautical miles from a surface mooring. Mean differences in the vector currents measured from the two current sensors at 36 meters depth were of order 3-4 mm/s, about 2% of the typical currents observed.

Data collected from our Warm Core Rings studies are being analyzed and used to determine the "velocity center" of the rings, map current structure relative to the ring center, and estimate the dynamic height distribution required to maintain the observed azimuthal currents. We hope, with the latter effort, to be able to make some definitive statements about the "reference level" velocity in a Warm Core Ring.

## SCATTEROMETER APPLICATIONS TO NUMERICAL WEATHER PREDICTION

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Long Term Objective: To improve numerical weather prediction using SASS wind data.

Approach: a) Development of a 4-dimensional Seasat analysis/forecast system to de-alias and assimilate SASS winds; b) Development and implementation of objective and subjective de-aliasing schemes; c) Comparison of forecast skills made from analyses with and without SASS data; d) Utilization of data generated from a simulated "nature" model to assess potential impact of scatterometer data.

Progress: An interactive analysis/forecast system was developed. A three-pass procedure utilizing the model first guess and available ship data was used to objectively de-alias Seasat data. In areas where the objective scheme was deficient (e.g., near the center of an intense cyclone), the chosen SASS vectors were subjectively checked and corrected on McIDAS. To date, five assimilation experiments have been conducted: 1) Control (rawinsonde, pibal, ship, aircraft, cloud-track winds, VTPR temperature soundings); 2) Control + SASS data; 3) Control w/o VTPR data; 4) Seasat w/o VTPR data; 5) Seasat with subjectively enhanced SASS data using the McIDAS.

A detailed evaluation of the impact of SASS data on large-scale numerical weather prediction was conducted for 7 SEP 78, 0000 GMT to 13 SEP 78, 1200 GMT. In general, the results showed that SASS data had a small effect when VTPR data was included in the assimilation and a larger effect when the VTPR was excluded. This indicated that some redundancy existed between the two data sets.

Objectively de-aliased wind fields were subjectively de-aliased and enhanced for the period 7 SEP 78, 0000 GMT to 10 SEP 78, 1200 GMT. Subjectively and objectively de-aliased winds were compared. These comparisons showed that the two fields were similar over approx. 80% of the globe, with substantial differences existing in the remainder of the data.

Experiments were conducted to assess the sensitivity of the GLAS 4th order forecast model to low level wind specification. Model forecasts were generated from initial conditions in which the correct 1000 mb or 1000 and 850 mb wind fields were replaced by the corresponding fields from 24 h earlier. The results indicated that the model forecast was sensitive to surface wind data where large analysis errors were present and that the effect of SASS data would be enhanced if higher levels were also affected in the analysis.

In a related project, a series of numerical experiments was started to study the impact of SASS winds on the forecast skill of the Navy's operational forecast model (NOGAPS). This involved reformatting all conventional and satellite data to allow the use of the Navy's system. as well as developing a sea level pressure analysis to replace the Navy's classified analysis. So far, the control experiment (without SASS data) has been run for the period SEP 7-13, 1978.

To accomodate the directional ambiguity of the SASS data, a rather unique analysis system was devised and tested (Hoffman, 1982). When a good first guess was available, e.g., from the 6 h forecast of a good NWP model, we found that the solutions were efficiently obtained by the conjugate gradient minimization method. The direct minimization approach was very promising because it could be extended to incorporate many types of data and constraints simultaneously. Current work is progressing on incorporating a nonlinear constraint of near balance among terms in the vorticity equation.

# GEOGRAPHIC VARIATION IN THE RELATIONSHIPS OF TEMPERATURE SALINITY, OR SIGMA-t VERSUS PLANT NUTRIENT CONCENTRATIONS IN THE WORLD OCEAN

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Long term interests include various aspects of phytoplankton behavior and physiology as they contribute to the optimization of primary production and the explanation of community development. Specifically, studies are underway concerning dinoflagellate diurnal vertical migration, the interaction of these behavioral responses with photic zone currents and the large scale variation in growth conditions for all phytoplankton groups.

The general objectives of the present research project are to investigate how reliably the concentrations of plant nutrients (nitrate, phosphate and silicate) can be predicted from temperature and/or salinity determinations throughout the world ocean. These predictions of plant nutrient concentration can be used to modulate a future primary productivity algorithm based on satellite determinations of chlorophyll a concentration (M-J Perry pers comm).

The approach used for this task begins with the acquisition of the appropriate subset from the NODC data base and of recent data from ongoing projects from areas of special interest. These data are divided into appropriate geographic units, displayed on x-y scatter plots for various factor combinations, gleaned of outliers far removed from the main trend, and statistically analyzed using polynomial regression techniques. The final result will be a series of tables including the coefficients of the regression relationships, the $r^2$ values for the overall relationships and 95% confidence limits for specific predictions.

During the first three months of this effort, the required computer hardware has been purchased, part of the NODC data base has been obtained and the required programs have been written and tested on a selected data base with good results. Additional progress awaits the complete acquisition of the required data base.

## AIR-SEA INTERACTION STUDIES

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Long term interests. Two areas of interest have been pursued under this contract: a) the relationship between wind stress and the surface wave spectrum, and b) the relationship between sea surface temperature features, meteorological conditions, and underlying oceanic features.

Objectives. a) With the study of wind stress and the gravity wave spectrum, we hope to better understand the role of the different scales of roughness on the sea surface in maintaining the wind stress on the ocean. b) With the sea surface temperature study, we wish to ascertain how representative remotely sensed sea surface temperature features are of underlying oceanic conditions.

Approach. a) During the MARSEN '79 experiment in the German Bight we obtained direct measurements of wind stress and wave height at the PISA mast 27 km west of the Island of Sylt. By simultaneous analysis of these two time series, we can study effects of the different scales in the wave spectrum on the atmospheric drag coefficient. b) During MARSEN '79 sea surface temperature surveys were obtained from aircraft with infrared radiometers by our German collaborator, V. Amann; several ships collected temperature and salinity data in detailed surveys which we have analyzed (with Portuguese colleagues, A. Fiúza and F.Sousa). By calculating the air sea fluxes of short and longwave radiation and turbulent stress, evaporation, and sensible heat flux, we could study their effect on the upper ocean.

Current status. a) About 40 hours of wind stress data have been calculated with the eddy correlation technique from the PISA observations. Mean wind speed has been corrected to 10 m height, with careful consideration of stratification. Tidal currents have been considered in evaluating surface velocity, and wave spectra have been calculated. Effects of the phase velocity of the various components of the wave field on the drag is now being evaluated. b) An article entitled "Sea Surface Temperature Patterns in the German Bight during MARSEN 1979" by Katsaros et al. (1983) has been written. It shows the consequences of periods of calm and solar heating in producing a shallow thermocline, which completely masks a topographic front in the area. Cooling and wind mixing restore the frontal features. These events are observed in NOAA6 satellite infrared images as well as in the aircraft and ship data.

This work is sponsored by NASA.

## VALIDATION AND APPLICATION OF THE SEASAT-SMMR GEOPHYSICAL ALGORITHMS

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Long term interest. Remote sensing of atmospheric and oceanographic parameters over the ocean from satellites.

Objectives of this specific task. In the past work we emphasized the validation of the Scanning Multichannel Microwave Radiometer (SMMR) channels which produce information about atmospheric water in vapor or liquid form. In the present work we use these channels to describe the distribution of water vapor, liquid water and rain intensity in midlatitude cyclones which crossed the Pacific Ocean during Seasat's lifetime.

Approach. We have selected portions of SMMR orbits which intersected the particular cyclones in question, and have gathered all available support information such as synoptic maps, satellite and ship data.

Current status. We have analyzed the SMMR products during the life cycle of two cyclones in detail, comparing them to National Meteorological Center analyses and GOES-West satellite visible and infrared images. The organization and evolution of the distribution of total atmospheric water vapor in reference to the cold, warm, and occluded fronts is very interesting and in general agreement with ideas developed from surface radar studies by Browning's group in England. Rain is usually organized in several large more intense cells along the cold front reminiscent of the pictures produced by Hobbs and co-workers at University of Washington. To further understand the value of SMMR products in locating the surface front and for prognostic purposes, we are presently reanalyzing the surface weather charts using all the ship reports.

This work is sponsored jointly by NASA and NOAA.

## NIMBUS 7-SCANNING MULTICHANNEL MICROWAVE RADIOMETER (SMMR) ATMOSPHERIC WATER

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Long term interests. I am interested in exploring the possibilities inherent in the totally new information of distributions of atmospheric and oceanic parameters that a Scanning Multichannel Microwave Radiometer (SMMR) can provide.

Objective of this specific task. The objective of this project is to test for accuracy of existing algorithms and possibly develop new ones for obtaining atmospheric water as vapor and liquid from the Nimbus 7 SMMR's brightness temperature measurements.

Approach. This project was started to take advantage of the information gathered by the University of Washington Cloud Physics Group during SMMR overpasses of the ocean west of the Washington coastline in February 1979. Comparison with rain gauges and radar coverage at a coastal station, aircraft cloud physics information, and careful synoptic analysis was planned.

Current status. SMMR rain rates calculated for five swaths which occurred along the Washington and Oregon coast in February and March 1979 have been compared qualitatively to National Meteorological Center analysis of frontal position, and quantitatively to rain gauge records along the coast. The areas where SMMR data show rain coincide beautifully with the expected region of precipitation around a synoptic front. This identification of precipitation is found in regions where satellite infrared and visible images show innocuous uniform cloud shields. By advecting the SMMR pixels onto the coast, and comparing to time averaged rain gauge records, we found that SMMR tends to underestimate the rain rate by a factor of two or more. An early experiment team version of SMMR brightness temperature with a team version of the rain rate algorithm has been used to date. Improvements in the quantitative estimate of rain rate are, therefore, expected.

This work is sponsored by NASA.

# ADVANCED OCEAN SENSOR SYSTEMS DEVELOPMENT

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Long Term Interest: The interest has been the development of precision passive microwave systems and algorithms for the remote sensing of the ocean.

Objective: The objectives of previous investigations have been the development and demonstration of passive microwave sensors to measure ocean surface temperature to within an absolute accuracy of 1°C and ocean surface salinity to within an accuracy of 1 ppt. The objective of the current research activity is to develop a passive microwave sensor whose frequency has been optimized to measure ocean salinity.

Approach: The past objectives were met with the 1976 overflights of the Chesapeake Bay utilizing a two frequency radiometer system developed at Langley. Latter demonstrations of this capability with improved systems were conducted along the Georgia coast in 1979, and again in the Chesapeake Bay area in 1980. In order to improve the accuracy of salinity measurements, a UHF radiometer was designed and developed. The activity this fiscal year was to complete the development and to evaluate performance during a Warm Core Ring flight test experiment.

Current Status: The development of the UHF radiometer system has been completed. Flight testing on-board a Wallops Flight Center p-3 aircraft was conducted during August 1982. These tests included overflights of a warm core ring and research ships collecting sea truth data during the August '82 warm core ring experiment. Interference from land based television stations radiating in the same UHF band as that used by the UHF radiometer prevented the collection of useful radiometer data even at distances away from land of up to 200 miles. Flight measurements of UHF radio frequency interference (RFI) have identified an RFI free band at 611 MHz. While this band is only 6 MHz wide and therefore not optimum for radiometric use in terms of sensitivity, it does provide an opportunity to test the UHF radiometer as a salinity sensor. Therefore, it is planned that the UHF radiometer system will be re-configured to operate from 608 to 614 MHz and flight tested during the Langley L-Band Pushbroom radiometer series of flight tests in 1983. Subsequently this UHF radiometer will be included in the inventory of remote sensors being used to complement the Large Space Antenna technology development at LaRC and the joint Soil Moisture Measurement program with GSFC.

# FLUORESCENCE STUDIES OF PHYTOPLANKTON PIGMENTS: A COMPARISON OF CLASSICAL AND LASER SPECTROSCOPY

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Research in marine optics at the USC Marine Microbiology Laboratory has been motivated by a desire to correctly interpret ocean color images as detected by remote radiometers such as the Coastal Zone Color Scanner. Previous work has shown that color changes are caused by differences in the phytoplankton crop within surface waters. Our laboratory has contributed to the advancement of marine optics by measuring the absorption and scattering properties of phytoplankton and bacteria.

The goal of this study is to determine whether laser-induced fluorescence of photosynthetic pigments in the sea will provide valuable information about the growth and distribution of marine phytoplankton. We wish to develop methods to measure the small scale distribution of phytoplankton in order to characterize the pigment composition of natural populations and determine primary production. This development is being carried out at JPL under a study entitled "Lidar and Acoustics Applications to Ocean Productivity", Dr. Donald Collins, Principal Investigator. The instrument under development in that study will make use of multiple excitation bands to detect fluorescence from various phytoplankton pigments. Our objectives are to guide the selection of excitation bands and to evaluate the energy requirements for an *in-situ* lidar system.

Our studies are carried out on cultures of the major taxa of marine phytoplankton. Absorption and fluorescence excitation spectra are determined using a home-built spectrophotometer/fluorometer. Laser wavelengths for subsequent studies are chosen from the results of classical spectroscopy. We have used both a Xenon-Chloride laser and Nitrogen pump laser pulsed at 20 Hz. Fluorescence and oxygen production are monitored simultaneously with a modified oxygen electrode system.

Our measurements on the green alga, *Dunaliella tertiolecta*, have confirmed earlier reports of decreased quantum yields of chlorophyll *a* fluorescence with increasing pulse energies. Such decreases in fluorescence yield were reported for the induced fluorescence of the freshwater green alga, *Chlorella vulgaris*; the process is reversible and has been called photon annihilation. We have also found that at high pulse energies, photosynthesis is irreversibly inhibited; the action spectrum for such a process is similar to that of the cells' absorption spectrum.

# COASTAL AND ESTUARINE DYNAMICS PROCESSES RESEARCH

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The objective of this task was to develop an atmospheric effects removal method. In 1978, the outline of an ocean-atmospheric radiance computation method was formulated and in 1979 the method was applied to a set of ocean radinace data collected by U-2 borne Ocean Color Scanner (U-2/OCS). Subsequently, several U-2/OCS application flights were conducted in the South Atlantic Bight. In November of 1981, the Shuttle-borne Ocean Color Experiment (OSTA-1/OCE) was conducted. All the data obtained from the above field experiments have been analyzed and the results published.

The results of the U-2/OCS experiment turned out to be considerably different from that of the Nimbus-7 CZCS. For this reason, this Goddard in-house activity has often been criticized by the CZCS team. Discussions of the derived relationships between the chlorophyll concentration and the "blue-to-green" ratio were presented in the open literature. Differences between the OCS and CZCS results can be attributed to the following facts:

a. The OCS and OCE experiments were designed with the intent of studying open ocean phenomena because we felt that the absorptive method would not be applicable to the coastal waters. In contrast, the CZCS team was interested in deriving a unified global chlorophyll algorithm which could be applied to both the coastal zones as well as to the global oceans. Therefore, the earlier CZCS team's results were based on a mixture of coastal and open ocean waters. Only recently the team began to isolate the radiance of the open ocean from that of mixed waters. There are signs that the large differences which previously existed are gradually narrowing in favor of our results.

b. The OCS and OCE are equipped with a proper atmospheric channel in the near-infrared which can be used directly to infer the aerosol concentration of the atmosphere. The CZCS is not equipped with such a channel. This poses a serious handicap for the CZCS atmospheric removal algorithms.

c. Both OCE and OCS were periodically calibrated against a known radiance standard as they are recoverable instruments. A satellite instrument such as CZCS cannot be easily recovered for a radiance check, and there is strong evidence that the CZCS's calibration has been drifting for some time.

This activity is being terminated after five years. The activity has served its purposes, however. The knowledge gained from this aircraft program has given us confidence in processing Shuttle data. It is regrettable that the program could not maintain a closer association with the Nimbus-7 CZCS program during its existence.

# SEASAT MAPS, LIBRARY, AND JGR ISSUE

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Long Term Interests of Investigators: Our long term interests regarding this activity are to develop methods and products which display oceanographic remote sensing data in such a manner as to enhance their use by the scientific community.

Objective of This Task: Our objectives are to evaluate the quality of data from the Seasat low rate sensors by comparing them to all available *in-situ* data. If the data are deemed to be of useful accuracy, we will consider publishing global maps. This activity also supports the Oceanic Remote Sensing Library, which provides library services to ocean researchers using the Pilot Ocean Data System. In addition, funds for the Journal of Geophysical Research (JGR) special issues devoted to Seasat are maintained here.

Current Status: Global maps of Seasat geophysical data products of various temporal resolutions have been produced. These are being compared with available *in-situ* data to assess the quality of Seasat data. The first special issue of JGR dedicated to Seasat geophysical evaluation was published in April 1982. The second special issue will be dedicated to science results from Seasat, and is due to be published in February 1983. Also, a special issue of Marine Geodesy dedicated to satellite altimetry will be published in 1983. The Oceanic Remote Sensing Library has been established and is being used by ocean researchers.

# USE OF CZCS IMAGERY IN ALBACORE TUNA STUDIES

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Distribution of Albacore Catches in Relation to Color Boundaries. CZCS imagery and albacore tuna catch data obtained from daily logs submitted by fishermen were used to investigate relationships between fishing success and ocean color boundaries. The rates of CZCS band 1 to band 3 radiance (blue:green ratio or $R_{13}$) were used to determine color boundary locations after atmospheric correction (Smith and Wilson 1981). $R_{13}$ was also converted to chlorophyll concentration ($C_{sat}$) according to Clark (1981) and Smith and Baker (1982). Catch data were normalized to 150 line-hours - a typical full day of fishing effort by an albacore jigboat. Normalized catch data for 7-day periods, from 3 days before to 3 days after each Nimbus-7 pass, were plotted on CZCS images.

Examination of the color imagery showed an intense color front located between the coastal and oceanic water masses. $R_{13}$ of the boundary was near 2.5. Chlorophyll concentrations in bluish, oceanic waters were usually less than 0.3 mg $m^{-3}$, and greater than 0.6 mg $m^{-3}$ in the greenish, coastal waters. Strong color fronts and high chlorophyll concentrations (up to 5.0 mg $m^{-3}$) were observed in near-shore coastal waters and associated with coastal upwelling. The color front marking the boundary between coastal and oceanic waters had a meandering north-south distribution with intrusions of oceanic water toward the shore.

Albacore fishing effort was distributed mostly in the oceanic waters with much lesser amounts in the coastal waters. The catch rates were highest in bluish, oceanic waters near the color boundary. Shoreward intrusions of oceanic waters had particularly large catches concentrated at the color boundary. Catch rates within the greenish, coastal waters were low or nil.

Movements of Albacore Tuna in Relation to Oceanic Fronts. CZCS and NOAA-6 satellite AVHRR data were used to investigate movements of albacore in relation to oceanic fronts. Satellite imagery was collected in conjunction with field experiments where acoustic telemetric methods were used to track horizontal and vertical movements of individual free-swimming albacore, and XBT observations were made to determine ocean surface and subsurface thermal structure. Three albacore were tracked for approx. 24 h and one for about 15 h. The results showed: a) total distances ranged from about 40 to 60 km, b) all fish remained in a finger of warm water which in the infrared satellite imagery appeared as an intrusion of warm water extending toward the coast separated from cool water to the north, inshore and south by about a $2^{\circ}C$ temperature gradient, c) tracked fish exhibited marked vertical excursions in depth with the range being larger during daytime hours than during nighttime hours, d) each of the fish spent the majority of the time in waters with temperature considerably lower (about $8^{\circ}$ to $15^{\circ}C$) than what has generally been believed to be the optimal temperature preference for albacore ($12^{\circ}$ to $20^{\circ}C$), and e) while undergoing vertical changes in depth, the fish frequently passed through a temperature gradient amounting to $7^{\circ}$ or $8^{\circ}C$, or about 3 to 4 times greater than the horizontal temperature gradient at the surface as indicated by ship measurements and satellite infrared imagery.

These findings indicate that the causal factors involved in the aggregation of tuna on the warm side of oceanic surface temperature fronts are not related to thermal-physiological mechanisms, as previously thought (Neil 1976). Instead, behavioral mechanisms related to feeding may be responsible. The author used CZCS measurements and a knowledge that tuna are visual feeders to provide evidence to support this hypothesis. The distribution of ocean color boundaries showed a gradient nearly coincident with the sea surface temperature gradient pattern. The diffuse attenuation coefficient (k) measured by CZCS showed a similar pattern, with lower values in warmer waters and higher values in cooler waters. The results showed that albacore remained in clear, warm oceanic waters and did not cross boundaries into turbid, cool coastal waters. Since water clarity affects the visual acuity of the tuna, and tuna are visual feeders, this factor may play a role in the aggregation of tuna on the warm side of oceanic surface thermal fronts, by affecting prey capture efficiency.

## Use of CZCS in Other Pelagic Fisheries Research

CZCS imagery is also used for describing ocean processes in relation to spawning of northern anchovy. Imagery was collected coincident with fine grid oceanographic ship observations. Preliminary results indicate that anchovy avoid areas of low chlorophyll concentration, presumably because of insufficient food availability. In addition, CZCS is being used to investigate distribution and abundance of juvenile salmon off the Oregon-Washington Coast. Imagery has been collected and processed, but as yet not all fishery data have been processed. CZCS appears to be a powerful tool for fisheries research. It can assist fishery scientists in describing marine habitats of fishes and in providing and environmental index for fish availability, which for tuna may be used to refine catch-per-unit estimates or to direct fishing effort. It also appears that chlorophyll measured by CZCS could be used as a biological environmental input for fish recruitment models.

# OCEAN CURRENT MEASUREMENTS BY SYNTHETIC APERTURE RADARS

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Long Term Interests: The long term goal of our investigators is to develop radar system concepts for quantitative measurements of oceanic phenomena.

Specific Objectives: The specific objective of our present research is to investigate the feasibility of measuring ocean current velocities by synthetic aperture radars (SAR). We will also examine the effects of various system parameters on the accuracy of such measurements.

Approach: We will examine the feasibility of two techniques for measuring ocean current velocities with SAR data. The first method utilizes a technique we developed to determine Doppler centroid frequencies of SAR data. The observed centroid frequencies should be Doppler shifted across an ocean current boundary due to current velocity. We will analyze Seasat SAR data obtained over several ocean current regions and determine if such Doppler shifts are detectable, and if the current velocity can be measured quantitatively. The second method utilizes changes in wavelength and direction of refracted wave patterns across current boundaries. Again, the data obtained by the Seasat SAR will be utilized.

Progress: We have processed an extensive set of Doppler centroid frequency measurements over various areas, such as the Gulf Stream, The English Channel, JASIN, etc. Preliminary results indicate that statistically significant shifts in the Doppler centroid frequencies were observable. These results are being confirmed with additional data.

# REMOTE SENSING OF AIR-SEA EXCHANGES IN HEAT AND MOMENTUM

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Long-Term Interests: Using satellite observation to study the exchanges of heat and momentum between the atmosphere and the oceans and their effects on ocean momentum and heat budgets.

Specific Objectives: There are two specific objectives at present: (1) to examine how the accuracy of Seasat-SASS winds vary with factors such as atmospheric stability and sea surface temperature, (2) to develop a method of estimating air-sea latent heat exchanges (monthly and mesoscale averages) from Seasat-SMMR observations.

Approach: (1) Average neutral winds and related parameters have been derived from FNOC ship reports and compare with SASS winds in areas of strong stability and temperature contrast, (2) the total water vapor in an atmospheric column is related to near surface humidity with data from radiosonde soundings. Near surface humidity can then be estimated from SMMR observations. Together with wind speeds and sea surface temperature observations from SMMR, latent heat flux can be evaluated and compared with those derived from ship reports with bulk method.

Current Status: In FY'82, three papers relating to the estimation of ocean surface wind/stress from scatterometer, L-band radar and surface pressure field were published. The study on comparing SASS winds with FNOC winds in areas of high stability and temperature contrasts are near completion and a paper will be submitted for publication in FY'83. Studies related to heat fluxes have begun. A study on mesoscale variation of sea surface temperature and heat flux will be completed in FY'83. Preliminary results on latent heat flux estimation from Seasat-SMMR observations are very promising and they will be presented in AGU Fall '82 Meeting.

# OCEAN CIRCULATION AND TOPOGRAPHY

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## Long Term Interests

To provide a physically unambiguous basis for the interpretation and quantitative utilization of satellite altimetry observations of sea surface topography and to assess the impact of this on relevant problems in ocean circulation. To develop analytical and interpretative techniques for determining the contributions of the ocean geoid, tides, barotropic effects and dynamic topography due to general and mesoscale ocean circulation phenomena to satellite radar altimeter measurements of the sea surface geometry. To conduct simulations and real data analyses to identify and formulate ways of achieving improvements in the computation of satellite orbits so that global orbital accuracies of 10 cm or better can be achieved.

## Specific Investigation Objectives

The specific objectives of the present work are to compute global as well as detailed regional maps of the mean sea surface topography from satellite altimeter data and to use these data as reference surfaces for the derivation of information on dynamic ocean processes. Such reference surfaces can be used for the detection of mesoscale variability in areas where detailed gravimetric geoids are not available.

## Approach

The major error source in computation of mean sea surfaces is radial orbit error. Over regions of a few thousand kilometers on a side, crossover adjustment techniques have been used to remove orbit error. On a global basis upgraded force models and data processing techniques have been used to reduce orbit error to less than 50 cm. The altimeter data referenced to the improved orbits are being gridded and contoured in the form of topography maps.

## Status

Regional maps of the mean sea surface have been computed in the N.W. Atlantic, the Gulf of Mexico, and the Bering Sea based upon the total set of GEOS-3 and Seasat altimeter data. The data have been adjusted to a regularized grid with a resolution of better than 0.25° and a precision of 10-20 cm. Detailed analyses of a global 1° x 1° mean sea surface based upon the GEOS-3 and Seasat data in combination with the best available long wavelength geoid (GEM L-2) have revealed the major features of the general ocean circulation.

# APPLICATIONS OF SATELLITE DATA TO OCEANOGRAPHY

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Satellite data are being applied to several areas of interest. These include: 1) high resolution sea surface temperature determinations over the POLYMODE region for inclusion as boundary conditions in a numerical model, 2) surface temperature and chlorophyll + phaeophytin gradients in the Gulf of Mexico for study of the Bluefin Tuna fishery, 3) co-linear Seasat altimeter tracks coupled with another numerical model to study dynamics in the Gulf of Mexico, and 4) correlations between current meter measurements in the Yucatan Strait with satellite-determined fluctuations of the Gulf Stream system.

In each area of research, the endeavor has been to use satellite data with other data in the hopes of obtaining synergistic effects. First, the techniques of correcting satellite data for atmospheric, instrumental, and/or orbital errors were critically reviewed, and, if necessary, improved. Data were then combined either with numerical models and/or ship or mooring data to study problems in ocean circulation. Results were analyzed for application to problems of scientific or economic interest. Data processing was accomplished using existing facilities, notably the image processor at the University of Miami.

Daily maps of sea surface temperature from GOES have been made for three months during the winter of 1977-1978 over the POLYMODE region at full 10 km resolution. RMS error is ± 1.4 K, but more than 90% of the data was cloud contaminated. The Bluefin Tuna fishery in the Gulf of Mexico was found to be three times more productive in 1980 than in 1979; satellite data were used to show that in the more productive year, fishing efforts were concentrated nearer the Gulf Stream boundary. Altimeter tracks of the Gulf eddies were used to document results, which suggested that the eddy separation period is about every nine months and not annual as previously thought. Current meters at the Yucatan Strait still showed correlations between eddy separation events and strong southward flow, and that these Gulf eddies accounted for 25% of the variance in the heat flux of the Florida Current off Miami.

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# DEVELOPMENT OF ISLAND STATIONS FOR SATELLITE READ-OUT OF IN-SITU SENSING OF ENVIRONMENTAL PROPERTIES

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Long Term Interests of the P.I.: Determine and understand the basic global processes operating now and in the past to form and alter the planets--their interiors, surfaces, oceans and atmospheres. Develop and apply technology for the study of the Earth and the other planets and satellites from space. Apply this new knowledge and technology to practical benefit. Educate and train students in these areas.

Objectives of This Specific Research Task: Develop a system of island stations in the Pacific Basin for the purpose of sensing environmental properties and transmitting them via satellite to the Honolulu laboratory computers. Implement specific measurements, such as sea level, water temperature, chlorophyll content, wind vector, rainfall, pressure, and make the systems available to other users.

Approach Used: Work with satellite communication equipment and sensor manufacturers to develop and supply appropriate devices, develop equipment and techniques in-house, test systems in the lab and at Honolulu harbor, install systems on remote islands and monitor their operation. Develop computer software to automate data receipt and station monitoring and to provide other users with data.

Progress: The project has been funded only since April 1982. Extensive debugging of Handar platforms has nearly resulted in a usable device meeting specs. A water temperature sensor was developed. Leupold & Stevens and incremental tide guages were interfaced to Handar platforms. PV power systems were developed. Full stations are operating in the lab, in Honolulu harbor and on Christmas Island. The CI station failed once (blown fuse) and was repaired. A station is about to be installed on Ponape. Sea level and water temperature are routinely measured and computer plots and numerical listings are produced. No publications have resulted so far.

# THE MAPPING OF OCEAN SURFACE CURRENTS USING DUAL-FREQUENCY MICROWAVE RADARS

Principal Investigator:

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The long term interest of this research is to establish the feasibility of making ocean surface current measurements with radars mounted on satellites. Preliminary results suggest that satellites in geostationary orbit may be suitable platforms for dual-frequency radars that can map ocean currents over areas as large as $10^7$km$^2$. However, the reliability of measuring current components using dual-frequency radars must be carefully established before serious consideration of this concept can begin.

To establish if dual-frequency radars can be used to reliably measure ocean surface currents, the following research objectives have been established for next year:

(1) Establish the limits on the signal-to-noise performance that dual-frequency radars can achieve by means of theoretical analysis.

(2) Demonstrate improvement of the overall system performance of a current sensing radar by applying signal processing techniques to existing dual-frequency data.

(3) Use the above results to determine system parameters required for an operational satellite-mounted current sensing system.

The approach utilized for this task is primarily theoretical but analysis of experimental radar data obtained by NASA and NRL researchers will be compared to theory whenever possible.

During the first year of this project, we have concluded a feasibility study that shows that current sensing radars mounted on two geostationary satellites can successfully map large ocean areas if appropriate signal processing techniques are used. We have also developed a theoretical model of a signal processing technique that enhances our ability to accurately determine the ocean current from cross-product spectra obtained from the received dual-frequency radar signal. During the next year, we plan to incorporate this model in studying the feasibility of other geostationary satellite configurations.

During the first six months of this grant, this work was partially sponsored by NASA Langley Research Center under grant NAGI-54.

# PLAN FOR THE DEVELOPMENT AND UTILIZATION OF OCEAN SURFACE DRIFTING BUOYS

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The long-term objective of this program is the development and use of surface drifting buoys for empirical studies of the general circulation of the upper ocean and lower atmosphere, their exchanges of heat, momentum, and energy, and their low frequency, large-scale variability (i.e., climate).

The objective of this specific research task was a one-year planning study for the development and use of surface drifting buoys. This research was extended at no additional cost for six months.

Seven scientists and six engineers from six institutions joined in a collaborative effort to refine the scientific objectives, assess the state of hardware, communications, and data handling as applicable to measurements from surface drifting buoys, and to develop a plan and organize a cooperative effort to address the above objective.

The group's activities included two meetings, January and September, 1981. The first meeting outlined the general approach to be taken, and individual working group assignments were made, and the second reviewed progress. The final plan has been developed and is being published by UCAR. In the meantime, communications between group members by the telemail system have been effective. The program was completed on schedule.

This work has been jointly sponsored by NOAA and NASA.

# GPS/Y-SET OCEAN NAVIGATION

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The objective of this activity was to develop software to post-process shipboard navigational data acquired from GPS (Global Positioning System) navigation satellites during conventional GPS/Y-set operation at sea.

This task is in its concluding stages at the present time. During the past year, covariance analyses showed that direct range-rate information is a valuable adjunct to pseudo-range measurements. Software capabilities were limited to X-set operation. User position was estimated using 14-state extended Kalman filter. The software has been validated using simulated data. Data reduction using the Endeavor cruise data revealed significant discrepancy between observed and computed pseudo-ranges. These discrepancies were determined to be due to tropospheric delays (ionospheric delays using dual frequency calibration were furnished by the user field test and instrumentation software). A polynomial correction based on an empirical formula furnished by Magnavox was incorporated into the software. The resulting agreement between observed and computed residuals was of the order of 1 to 2 meters over short spans of observation. Expected GPS measurement uncertainty in pseudo-range is four meters.

Data analysis activities are in progress. Preliminary reductions of the Endeavor data reveal that the software performance, when compared to the filter states derived by the on-board GPS/Y-set navigation computer, is measurable by an improved quality of data fit and smoother velocity and hence position estimates. Clock states are in good mutual agreement. The software is able to cope with maneuvers executed by the research vessel. However, some systematic signatures prevail in the data residuals. This aspect is being investigated to further enhance performance.

The New Horizon data appear to be similar in character to the Endeavor data, as discernible from uncertainty in velocity estimates. Reduction of New Horizon data is deferred until the sources of systematic signatures are identified, and until filter parameters are modulated to enhance filter behavior.

# COMMERCIAL APPLICATIONS DEMONSTRATION PROGRAM

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Long Term Interests: Observations of the ocean surface from satellite platforms have commercial applications. Surface wind and wave measurements can be used to improve marine weather forecasts, thereby impacting the operational activities of marine industries, including off-shore oil and gas operations, marine transportation, deep sea mining, marine safety, and commercial fishing. Sea ice observations play a major role in arctic operations, and color measurements have shown real promise in identifying key water masses important to fisheries research and commercial fishing tactics. Studies with industry continue to show that synoptic ocean observations from Seasat and Nimbus-7 have real commercial utility which translates into economic benefits from increased fuel efficiencies, reduced hull and cargo losses, and improved scheduling in off-shore operations. Through a series of cooperative experiments involving NASA, NOAA, and industry, the utility of satellite oceanography in commercial applications can be demonstrated.

Specific Task Objectives: The objective of this task is to assess the utility of the Nimbus-7 Coastal Zone Color Scanner (CZCS) in commercial fishing applications. A further objective is to aid the transferral process of CZCS technology from the research domain to an operational status within both the NOAA community and commercial ocean industries.

Approach: In a series of applications experiments, CZCS data of the U.S. West Coast will be processed and delivered to selected fishing vessels in a near real time basis for use in establishing fishing tactics. These data will also be collected once per week by the Scripps Institution of Oceanography Remote Sensing Laboratory. Charts depicting ocean color boundaries and major color differentiated water masses will be prepared by the Visibility Laboratory for subsequent radio-facsimile transmission to participating vessels through NOAA/NWS (National Weather Service) and U.S. Coast Guard facilities. False color CZCS images in photographic print format will be sent by mail to Marine Advisory Agents in California and Oregon ports. An evaluation will be conducted with participating fishermen. The applications experiments will be conducted over two fishing seasons.

Current Status: Facsimile charts and photogrphic prints continue to be transmitted to participating fishermen. Significant use of the CZCS has occurred in the albacore and swordfish fisheries. Work by R. Michael Laurs of the National Marine Fisheries Service-Southwest Fisheries Center has definitively shown the correlation between water color and commercial albacore catches. A final evaluation of the experiments is scheduled to be completed by early 1983. Commercial fishing interests are encouraging NOAA to continue processing and distribution of CZCS data to fishing vessels. Other support for this work has been received from NOAA-NWS.

# EFFECTS OF ENVIRONMENTAL STRESSES ON THE PHYSIOLOGY OF MARINE PHYTOPLANKTON: IRON AND MANGANESE DEFICIENCIES

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I am interested in the influence of hydrographic boundaries on the distribution of phytoplankton species and color groups, and on the importance of differing trace metal conditions on defining hydrographic boundaries.

The objectives of this research are to study the effects of iron and manganese on growth-rate characteristics and identify how these influence fluorescence excitation spectra of phytoplankton from various environments of the open ocean. The long-range goals are to predict trace metal effects on natural communities, especially as these effects account for observed differences in eutrophic and oligotrophic waters, better elucidate the role of these metals in photosynthetic cellular energetics, and determine the effects of these metals on spectra as perceived by remote sensing.

The approach is to evaluate the role of the trace metal nutrients, iron and manganese, on photosynthesis as evidenced by changes in fluorescence excitation spectra, pigment composition, growth rates, and trace metal cell quotas. Trace metal stresses can be expected to cause several types of effects on the physiological processes of marine phytoplankton which would cause changes in their fluorescence excitation characteristics: changes in photosynthetic rate, structural changes in chloroplasts, changes in chloroplast migration rates, and changes in pigment concentrations. The correlation of specific spectral changes with specific physiological changes should provide insight into factors governing distribution, biomass and spectral properties of phytoplankton.

The research is nearing the end of the first year of a projected three-year study. During the first year, I have determined growth rates and fluorescence excitation spectra for 26 different clones representing all major color groups under control conditions. I have detailed data of growth rate, chlorophyll a, and fluorescence spectral changes under iron and manganese deficiencies in four clones representing three color groups. Two of these clones have been studied extensively for cell quotas in iron and manganese under different iron and manganese culture conditions. Pigment analyses have begun. At this point, it appears that the characteristics of light absorption by phytoplankton can be affected, in some species, by trace metal deficiencies.

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## *SEA SURFACE TEMPERATURE WORKSHOP*

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*A Sea Surface Temperature (SST) Workshop activity has been initiated by NASA as a means for assessing the present state-of-the-art in measuring global SST's from space. Substantial progress has recently been reported on the accuracies of SST's derived from various satellite instruments. An unbiased scientific assessment of these sensor capabilities is therefore necessary as a prelude to the planning of future marine surface observation missions with a sea surface temperature component.*

*The objective is to design and conduct a scientifically controlled experiment to evaluate the relative accuracies of four satellite SST sensors for the same time periods and areas. The sensors are the AVHRR, HIRS/MSU, SMMR, and VAS. Subsequent objectives will be to identify the relative strengths and limitations of each method for operational and reserach use, and to recommend future hardware and software directions. The workshop will use the facilities of the NASA Pilot Ocean Data System.*

*The approach currently planned for the workshop is to identify a number of time periods and regions for which all sensors were operating satisfactorily. SST's will then be generated from the sensor data using current algorithms, on temporal and spatial scales appropriate to each sensor. In parallel, high quality in-situ SST data will be assembled, and all data sets will be installed on the PODS computer system for analysis. Consistent analysis techniques will then be applied to each data set, and the results examined at a special workshop to be held for this purpose in mid-1983. A report will be prepared documenting the proceedings and conclusions of the workshop. In addition, major research findings of the workshop will be collected together in a series of papers for publication in the open literature. A meeting of workshop investigators will be convened for Fall 1983 to report on further evaluation of workshop data sets and to make recommendations for future satellite instruments.*

## MICROWAVE REMOTE SENSING OF OCEANOGRAPHIC PARAMETERS

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Long-Term Interest: To advance the use of passive microwave techniques, both alone and in conjunction with other remote sensing and in-situ methods, for measurement of oceanographic phenomena from space. These measurements to be applied to the understanding of problems in oceanography, ocean-atmosphere interactions, and the cryosphere.

Specific Research Objectives: The emphasis of current work is to analyze the measurement performance of the SMMR instruments on Seasat and Nimbus-7, to improve the measurement accuracy through refined retrieval techniques, and to demonstrate the application of the data to oceanographic problems. Optimization procedures are being investigated to determine sensor configurations (frequencies, view angles, etc.) and efficient data processing for future passive microwave sensors.

Approach: Ten-day and monthly averages, on a global 2°x2° grid, of the four major SMMR parameters (SST, wind speed, water vapor, and cloud liquid water) have been generated and contoured on the PODS using the Seasat GDR data set. These maps are being examined and compared with other data sets both spatially and in time-sequence to determine the stability and accuracy of the SMMR on these scales. The same approach will be used for examining Nimbus-7 SMMR data. The Nimbus data will be processed selectively from the raw data level (TAT tapes) using modified antenna pattern and geophysical retrieval techniques. Modeling studies will investigate the effects of ocean and ice features on microwave emission over a wide range of frequencies.

Current Status: Analysis of the SST maps has demonstrated the SMMR ability to correctly show the major large-scale ocean features with sufficient accuracy to monitor month-to-month changes in these features. A high bias has been observed in cold ocean regions, showing the need for a small non-linear correction in the retrieval algorithm. SMMR winds have been compared map to map with SASS and ALT winds and show good agreement in spatial variability. Nimbus TAT tapes have been processed selectively to the brightness temperature stage, at which they are being examined for anomalies prior to geophysical retrievals. Modeling studies are underway for algorithm and sensor optimization. The effects of ice anisotropy on microwave remote sensing data have been shown to be significant, and more precise data are being incorporated to make the models more realistic.

# COUPLED ICE-OCEAN DYNAMICS IN THE MARGINAL ICE ZONE

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## Long Term Interests

The P.I. uses analytical and numerical models to elucidate the physics of upper ocean circulation. The present NASA contract deals with the 2 - 15 day time scale of the ocean circulation near and under the Marginal Ice Zone (MIZ).

## Objective

The P.I. has a long-term program to develop new models of the atmosphere-ice-ocean dynamics in the MIZ. We wish to understand the effect of ice hydrodynamics and thermodynamics on the adjacent ocean circulation.

## Approach

Numerical and analytical models are used. The initial work assumes the along-edge ice scales to be small. Four papers have been written. The work underway extends the models to include the along-edge coordinate and thermodynamics (melting + freezing). Dr. L. P. Røed, University of Oslo, is heavily involved (funded) in this work. An important problem yet to be solved is the formulation of the constitutive equations for the marginal ice zone for a 2-dimensional ice field. New numerical methods need to be developed for handling the moving ice edges. We hope to study the baroclinic instability of the MIZ and the mechanisms for formation of ice bands.

## Current Status

Two papers have been accepted or published (Røed + O'Brien, 1981, 1982). Two papers are in review, (Røed + Smedstad, 1982 and Røed, 1982). Dr. Røed is concentrating on including thermodynamics. Dr. O'Brien and his Ph.D. students, Ms. Hakkinen, are working on formulating the constitutive equations for an (x,y,t) ice model. Dr. Roisin will assist in the theoretical construction of the dynamics.

# C-BAND MEASUREMENTS OF RADAR BACKSCATTER FROM ICE

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CO-INVESTIGATOR: R.K. Moore

LONG-TERM INTEREST: To ascertain quantitatively the ability of radar systems to measure relevant properties of sea ice and to determine the optimum parameters for radar systems that can make such measurements. In general, the application of microwave remote sensing to sea ice research problems and understanding the underlying physics.

OBJECTIVE: Acquire radar backscatter data of sea ice over the 4-8 GHz frequency range, as supplemented by 8-18 GHz data from other programs. Numerous measurements of backscatter from ice have been made in other frequency bands, but no data existed between 1.5 and 9 GHz. These data will be used to describe the utility of a radar operating at C-band frequencies.

APPROACH: A series of remote sensing experiments coupled with extensive ice characterizations has just been completed. The first of these, conducted at Mould Bay, N.W.T., during October 1981, focused on the characteristics of newly formed ice and multiyear ice at the start of the growing season. Ice in the Gulf of St. Lawrence was examined in February, first-year and pancake ice in the North Atlantic in March, and ice at Mould Bay during June. The June experiment focused on both first-year and multiyear ice during the melt season. These varied data sets will be used to further improve criteria for instrment system design and to aid in the image interpretation once the instruments are in operation. Measurements were also made at 1.5 and 8-18 GHz frequencies (related work sponsored by ONR). These data will be analyzed and a comparison of scattering coefficients will be made. Collaboration will take place with Rene Ramseier of RadarSat and Tom Grenfell of the University of Washington in the ice characterization measurements and active/passive microwave measurements. Future investigations are planned to investigate the microwave properties of the Marginal Ice Zone in the Bering and East Greenland Seas.

STATUS: Significant progress has been made in the reduction of the above data sets. We are currently occupied with data analysis and preparation for reporting the results.

Related work is supported by ONR.

# TIME DEPENDENT ALTIMETER STUDIES

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Long Term Objectives: To investigate two-dimensional mapping of altimeter data in order to separate the mean and time varying components of the altimeter signal. The mean is related to marine geology. Time varying signals include tides, and current and mesoscale eddy variability. Of especial interest is the conversion of altimeter data into estimates of the ocean tide, as seen by conventional gauges both in coastal areas and the deep sea.

Specific Objectives: (1) Patagonian Shelf: To generate shelf models of the Patagonian Shelf tide, using a barotropic finite difference model with adjustable dissipation. Comparison of these models with altimeter height values should allow a better understanding of the shelf tide. A key objective is an estimate of the M2 shelf dissipation.

(2) Global Tide: With new high precision orbits that are now available, partial determination of the M2 tide from Seasat dat is possible. A modified response analysis will be used, and the results compared with existing models. This form of analysis should be ideal for the addition of data from future missions.

(3) Pre-TOPEX: The models of Shwiderski and Parke and Hendershott are being compared to determine areas of disagreement. Understanding the source of disagreement should be useful for future modelling efforts and should serve as a guide for future measurements.

(4) Mean Sea Surface and Residual Variability: The mean sea surface is strongly related to the geology of the ocean floor and crust. The residual variability in contructing this surface provides a statistical view of short length scale (less than 500 km) ocean variations during Seasat.

(5) Although the Seasat mission was short, it should be possible to map some real variations in ocean height in the 300-2000 km length scale range. Areas for investigation are the Somalia eddy off Somalia, and the Antarctic Circumpolar Current.

Status: Models of the Patagonian Shelf are currently being generated. A crossing point file for use in the global tide analysis is being completed. Comparison of spherical harmonic coefficients for the Shwiderski and Parke and Hendershott M2 tide models, surprisingly, show significant differences, with a 20% difference in the second harmonic. A mean sea surface has been generated. A high pass view of the surface is being prepared as an overlay for the new Scripps Jebco bathymetric charts, and will be published as an official Scripps series.

# STUDIES IN SEA ICE MODELING

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Long-Term Interests: Long-term interests include improved sea ice modeling, coupled ice-ocean, ice-atmosphere, and ice-ocean-atmosphere modeling, climatic change, and sea ice both as an indicator of climatic change and as an important interactive component in climatic change.

Objective: The objective of this task is twofold: (1) examine with a numerical sea ice model the occurrence of the Weddell polynya recorded in the 1974-1976 southern ocean data sets from the Nimbus 5 Electrically Scanning Microwave Radiometer; and (2) (with R. Bindschadler, GSFC) quantify the response of Antarctic sea ice to possible atmospheric temperature increases.

Approach: In each case numerical calculations are done with the thermodynamic/dynamic sea ice model described in Parkinson and Washington (1979, JGR, 84, 311-337). (1) The approach is to use the sea ice model to simulate both years with a Weddell polynya and years without a Weddell polynya, by varying the input fields, and then to analyze the causes of the contrasting results. (2) The approach is to run the sea ice model for the full southern ocean with mean-monthly climatological data as a standard case, then with air temperatures uniformly increased by 1 K, 3 K, and 5 K, and finally with air temperatures increased with the spatial and temporal dependence predicted by atmospheric general circulation models for a doubling and quadrupling of atmospheric $CO_2$, and to analyze resulting 38-month time sequences of such variables as the total area of ice and the latitude of the ice edge at specific longitudes.

Current Status: (1) The computer runs have been completed for the polynya study, and the results, which establish the input wind fields as the dominant influence on the formation of the modeled polynya, are being written up for publication in JPO. No polynya forms with spatially-uniform winds, whereas in the event of non-uniform winds, a polynya forms in the location of a prominent high or low pressure system. (2) Results for the standard case and cases with uniform temperature increases have been generated, revealing a pronounced regional dependence and a non-linearity in the response of the ice cover to temperature changes. On a hemispheric average, the winter ice edge retreats 2° latitude with a 1 K temperature increase and 6° latitude with a 5 K temperature increase.

## STUDIES IN OCEAN/ICE COUPLING

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Long-Term Interests: These include the interaction of sea ice dynamics and thermodynamics with the ocean and atmosphere, the role of sea ice processes in climate change, and an understanding of the utility of sea ice distributions as an indicator of the climate state.

Objectives: The objectives of this task are to examine the nature of ice-ocean coupling through numerical modeling, and to identify and analyze the important processes affecting ice-ocean interactions.

Approach: This involves coupling numerical models for sea ice and the upper ocean and analytically examining the basic principles affecting the coupling. The sea ice model employed is the thermodynamic/dynamic model described in Parkinson and Washington (1979, JGR, 84, 311-337), and the ocean model is the two-layer model described in Schopf and Cane (1982, JPO). The two models require alterations to run compatibly and to include the major interactive ice/ocean components. This involves adjusting the ocean model to run on the grid of the sea ice model, inserting the sea ice model calculations to the coding for the ocean model, adding salt to the ocean density calculations and a salt flux to the ice calculations, adapting the ocean model to allow for deep convection, and adjusting appropriately the heat flux and momentum transfers between ocean and atmosphere in the presence of an ice cover. After the coupling has been successfully accomplished, idealized studies over a wide range of parameters will be undertaken to identify the limits on the interactive physics. Subsequent modeling studies will refine the analysis and begin to simulate polar conditions, with important initial aims being to examine the ways in which the ocean can provide heat flux at the base of the ice, the impact of the heat flux on sea ice distributions, and the sensitivity of the ocean circulation to sea ice behavior.

Current Status: The numerical details of coupling the model codes are being attended to. The coding relevant to the sea ice grid has been added to the ocean model, which is now being altered to run on the Cyber computer. A salt parameterization has been devised for the ice calculations and is being inserted into the ice model.

# OCEAN WAVE MEASUREMENT BY ANALYSIS OF RADAR IMAGES OF THE OCEAN

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Long-Term Scientific Interests: Synthetic aperture radar (SAR) images contain information regarding ocean surface phenomena on spatial scales from $\sim 10$ m to $\sim 1000$'s km. SAR image brightness responds to changes in small scale ($\sim 30$ cm) surface roughness, to larger scale surface dynamics which modulate the small scale roughness and to surface motion through Doppler effects. Our objective is to interpret brightness variations in terms of ocean phenomena, e.g. long gravity waves, currents and current gradients, sea surface temperature gradients, winds, internal waves, ship wakes and surface films.

Research Task Objective: Using optically imaged SEASAT SAR data we are investigating the measurement of long ocean waves, particularly the directional wavenumber spectrum $\Psi$ in the range 50 to 800 m. Our objective is to assess the limitations of $\Psi$ measurement by SAR and, within these limits, to put SAR measurement of $\Psi$ on a firm quantitative footing, both theoretically and experimentally including applications to wave evolution in the open ocean and coastal waters.

Research approach: Our approach to wave measurement by SAR is to: i)calculate the $2^{\underline{d}}$ wavenumber (Fourier) spectra of SAR images correcting for instrument response, ii) compare SAR spectra with surface buoy spectra to find experimentally the relationship between SAR image spectra and buoy spectra, iii) model the radar wave-ocean wave interaction and iv) apply the model to estimate $\Psi$ from SAR images, comparing the results with buoy measurements. This research is done in collaboration with Drs. W.R. Alpers (Max Planck), F.I. Gonzalez (NOAA/PMEL), R.A. Shuchman (ERIM), and R.H. Stewart (Scripps/JPL).

Current Status: We have finished our initial analysis of wave observations using optically processed SEASAT images and surface buoys during the JASIN experiment. Major conclusions are:

1. SAR images yield estimates of dominant ocean wavelength and direction with average errors of $\approx 14\%$ and $\approx 10°$ respectively.
2. Visibility of ocean waves in SAR images is largely limited by: $H_{1/3} \lesssim 1$ m, windspeed $\lesssim 3$ ms$^{-1}$ and inadequate SAR resolution.
3. SAR image spectra are in rough agreement with buoy measurements of $\Psi$ and correspond less closely with ocean wave slope spectra $\Psi'$.
4. It may be possible to use SAR images to estimate $H_{1/3}$ since the peak SAR signal to noise ratio is correlated with $H_{1/3}$.
5. These data and comparisons lend qualitative support to the theory of Alpers, Ross and Rufenach (1981).

This research was jointly sponsored by ONR, NOAA and NASA.

# INTERPRETATION OF SEASAT SAR IMAGES IN TERMS OF OCEAN SURFACE PARAMETERS USING SPECIALLY PROCESSED DATA FROM THE JASIN AND GOASEX EXPERIMENTS

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Long-Term Scientific Interests: Synthetic aperture radar (SAR) images collected by aircraft or satellite contain information regarding ocean surface phenomena on spatial scales from $\sim$ 10 m to $\sim$ 1000's km. SAR image brightness responds to changes in small scale ($\sim$ 30 cm) surface roughness, to larger scale surface dynamics which modulate the small scale roughness and to surface motion through Doppler effects. Our objective is to interpret brightness variations in terms of ocean phenomena, e.g. long gravity waves, currents and current gradients, sea surface temperature gradients, winds, internal waves, ships, wakes and surface films.

Research Task Objective: Since digitally processed SAR images are more consistent and generally superior in quality to optically processed images, we are now using digitally imaged SEASAT data in our investigation of ocean wave measurement by SAR. Our objective is to understand the physical processes by which ocean surface phenomena, e.g. surface waves & internal waves, manifest themselves in SAR imges. In particular we are trying to put SAR measurement of the directional waveheight spectrum $\Psi$ on a quantitative footing, theoretically and experimentally including applications to wave evolution in the open ocean and coastal waters.

Research Approach: Our approach to understanding how waves are imaged by SAR is to: i) obtain digitally imaged SEASAT SAR data relevant to the JASIN and GOASEX experiments, ii) calculate the $2^{d}$ wavenumber (Fourier) spectra of the images correcting for instrument response, iii) compare SAR spectra with surface buoy spectra to determine experimentally the relationship between these two quantities and iv) compare the experimentally determined relationship with the predictions of relevant theories. This research is done in collaboration with Drs. W.R. Alpers, F.I. Gonzalez, S. Peteherych, and R.H. Stewart.

Current Status: Initial analyses of wave observations during the JASIN and GOASEX experiments using optically imaged SAR data have been completed. We have just started a continuation of this work using digitally imaged data from the JASIN experiment. At this point we have three images from orbits 762, 1044 and 1049. These images are kindly provided by the Remote Sensing Center of DFVLR near Munich. We have developed the software needed to read the DFVLR data tapes and are now adapting existing programs to provide correction and display of the image transforms.

# STUDIES OF SHELF CIRCULATION UTILIZING A BOTTOM-MOUNTED ACOUSTIC DOPPLER PROFILING CURRENT METER

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Long Term Interests: Principal research interests related to this project are the dynamical description of shelf circulation features and the development and evaluation of new ocean instrumentation.

Specific Objectives: Specific objectives of this research task are (1) The development and evaluation of a bottom-mounted doppler acoustic profiler which is capable of horizontal velocity measurements over 100+ meters of the water column with a vertical resolution of 2m and an accuracy comparable to that of mechanical current meters; and (2) Utilization of the fine vertical resolution of the acoustic doppler measurements to examine the detailed structure of coastal currents.

Approach: A self-contained bottom-mounted Recording Doppler Current Profiler (RDCP) was constructed and deployed for several months on the Northern California Shelf. The RCDP was positioned adjacent to a conventional current meter mooring in order to facilitate evaluation of profiler performance through a detailed intercomparison.

Status: Data handling and analysis software have been developed and preliminary analysis completed. Data from the current meter mooring have not yet been made for intercomparison.

# SURFACE WAVE AND TURBULENCE PHENOMENA ASSOCIATED WITH REMOTE SENSING

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The long term interests of the principal investigator include the development of quantitative relationships between signals obtained by remote sensing, particularly synthetic aperture radar, and the properties and structure of surface waves and surface currents in the ocean.

This specific research task is concerned with the interaction of short wave components (at a fixed wavelength, as sensed by SAR) with surface currents produced by oceanic eddy structure. The investigation involves both theoretical analysis and experimental study, the latter in collaboration with Dr. Norden Huang's group at NASA-Wallops.

A series of numerical experiments has been undertaken to calculate the response of the surface wave spectrum, measured at a single (short) wavelength to a variable current field. In the case of a simple shear, there are no caustics in the field and the variations in spectral density (proportional to the variations in back-scattering cross section) arise from the turning of the short wave components by the current; they are smeared out by regeneration by wind. Calculations are planned for flow fields in which caustics are present -- examples of this include the flow over shallow bottom topography and near moving oceanic fronts.

A series of measurements of the interaction between a group of long waves with shorter, wind generated waves was made by Ms. Kaye Burnett during a previous year. The results are now being analyzed. When the ratio of wind friction velocity to wave speed is of order one, the interactions are strong, with a suppression of the short wave activity during the passage of the long wave group, followed by an amplification before subsequent relaxation to the general saturation level. Work is being continued in both of these areas.

# ACOUSTIC APPLICATIONS TO OCEAN PRODUCTIVITY

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Our long term goals are to understand the dynamics of biological productivity in the upper mixed layer of the ocean. Techniques exist for estimating phytoplankton biomass and variability on small scales. These can be related to large-scale chlorophyll maps from satellite sensors. Biomass, however, is not a direct indicator of primary productivity. The remotely sensed chlorophyll measurements represent only that portion of the biomass which remains after zooplankton grazing. Thus, our understanding of oceanic productivity and variability must also include the impacts of, and the interrelationships between, the zooplankton and phytoplankton.

This project is for the biological and oceanographic portion of a joint USC and JPL (D. Collins, Jet Propulsion Laboratory) program to develop and test an acoustic technique (chirp sonar) to measure zooplankton distributions in the ocean. This zooplankton component will be integrated with other projects which are developing laser sensors to concurrently measure phytoplankton biomass, temperature, and salinity variability in the upper mixed layer.

The approach is to modify a chirp sonar, previously developed at JPL, to operate at ultra-high acoustic frequencies needed to record scattering from zooplankton. The return signal from the chirp sonar will be range gated into a finite number of bins between the underwater transducers and 30 to 50 m from the source. To confirm the hypothesis that the recorded scattering is from the zooplankton, plankton samples will be collected with a high-volume pumping system. Samples will be identified and the predicted scattering will be calculated from existing scattering models for zooplankton developed at USC. The calculated scattering values will be compared to the chirp sonar measurements.

The chirp sonar was tested at frequencies of 0.44, 0.88, and 2.23 MHz. Concurrent zooplankton samples were collected, sorted, identified and run through the predictive scattering models. Measured scattering at 0.88 MHz did agree with calculated values from the pump samples which indicated initial validation for the technique. The transmitter and receiver for the chirp are presently being redesigned and a second test is planned.

# OCEANOGRAPHIC AND METEOROLOGICAL RESEARCH BASED ON THE DATA PRODUCTS OF SEASAT

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Long Term Interests: To contribute toward improved numerical computer based weather, ocean circulation, and ocean wave predictions. The approach is to utilize more accurate initial value specification of the synoptic scale planetary boundary layer over the oceans (with mesoscale effects correctly filtered out). This may be derived from data from satellite sensors such as scatterometers, passive microwave radiometers, infrared and visible sensors, atmospheric sounders, and altimeters.

Objectives of Present Research: (1) To understand the effects of communication noise and attitude errors when compounded with the effects of mesoscale turbulence. This allows definition of the sampling variability of scatterometer wind measurements, and derivation of synoptic scale wind fields, divergence fields, wind stress fields, and the field of the curl of the wind stress from the SASS data. (2) To study the effect of a six hour data window on SASS data assimilation. (3) To study the concept of whether backscatter is best related to wind stress as opposed to the wind directly. (4) To study mesoscale turbulence.

Approach: As enumerated above, the approaches are (1) to use the dealiased SASS-1 Goasex winds provided by NASA Langley to be extended to six days of global dealiased SASS-1 data developed by Dr. S. Peteherych, (2) to simulate Seasat passes with the "frozen" orbit over extratropical cyclones, (3) to collaborate with Dr. Mark Donelan and use his soon to be completed research results, and (4) to use data provided by Dr. Donelan and theories being developed by Prof. C.M. Tchen of City College.

Current Status: As above, (1) initial results are to be published in Journal of Geophysical Research and the theory has been developed based on an extension of the work done for the S-cubed committee (data processing programs to generate the various fields are being written), (2) a report exists in draft form written by Dr. Winfield Sylvester, (3) a visit with Dr. Donelan is planned for December, and (4) some theoretical results appear to be imminent.

# RADIATIVE TRANSFER MODELING OF OCEANOGRAPHIC LIDAR SYSTEMS

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The objective of this research activity was to develop modeling techniques for investigating the effects of underwater radiative transfer mechanisms on the performance of oceanographic lidar systems. Emphasis was on airborne fluorosensors. The activity was terminated at the end of FY 1982 as part of the phaseout of marine science remote sensing research at Langley.

We developed a semianalytic lidar radiative transfer model (SALMON) using a hybrid approach which combined conventional Monte Carlo simulation techniques with analytic calculation of statistically expected values. A series of computer studies was performed to demonstrate the efficiency of the model, establish its physical validity, and demonstrate its usefulness in typical airborne fluorosensing missions.

During FY 1982, SALMON was completed for application to an airborne lidar system measuring Mie backscattering, water Raman scattering, and chlorophyll a fluorescence in a homogenous medium. Model results compared well both qualititatively and quantitatively with laboratory measurements of Mie backscattering from suspensions of Teflon spheres. The model was also used to simulate a typical airborne fluorosensing system. The results provided useful information on the performance of integrating fluorosensors as a function of laser excitation wavelength and chlorophyll concentration. Five articles describing this research were published or accepted for publication during the fiscal year.

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# REMOTE SENSING OF THE COASTAL OCEAN AND A LARGE LAKE BASIN: COMPARISON WITH THE STATISTICS OF CHLOROPHYLL AND TEMPERATURE PATTERNS DERIVED FROM FIELD DATA

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Long Term Objectives: The spatial and temporal distributions of organisms in the sea are controlled by various physical, chemical, and biological factors. We seek to identify those processes which dominate in a given region for a specified period and over what spatial and temporal scales they act. We are particularly interested in distinguishing physical (and chemical) factors from biological processes.

Specific Objectives: (1) Test the utility of synoptic satellite imagery in extending or replacing field measurements of chlorophyll and surface temperature on several different spatial scales, (2) characterize and quantify chlorophyll and temperature "patch" distribution in different regions of the lake and coastal ocean, and (3) attempt to explain the forces which govern the formation and transformation of these patterns.

Approach: We have collected images from the CZCS (on NIMBUS-7) and AVHRR (on NOAA-6 and TIROS-N) that contain Lake Tahoe, California-Nevada, and the west coast of British Columbia, Canada. The images coincide with previous field measurements of the three-dimensional chlorophyll and temperature fields in these water bodies. We will compare the various statistics that emerge from an analysis of the spatial patterns seen in both satellite images and field measurements. Indicators include covariance and correlation statistics, spectral and coherence estimates, and empirical orthogonal functions. We will investigate whether subsurface measurements (perhaps depth-averaged measurements) reflect the information obtained via satellite and the extent to which external factors, like wind speed and solar radiation, predict the observed patterns.

Status: We have identified, collected, and archived 280 images. All are registered to uniform grids for each region. We are presently removing contamination due to clouds from AVHRR imagery. Application of algorithms which convert radiances from CZCS imagery to chlorophyll concentration began in December 1982. Preliminary analysis of temperature data reveal patterns in Lake Tahoe that are predicted by a numerical circulation model. Visual inspection of CZCS images show discontinuities that agree with those seen in field data. Patterns off British Columbia are more complex. Detailed interpretations await comparisons with maps obtained from objective analyses of field data. Application of a two-dimensional turbulence model shows patterns that are similar to that obtained from satellite imagery.

# MEASUREMENT OF CURRENT PROFILES USING A DOPPLER ACOUSTIC LOG

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We seek to describe the variability of ocean currents on vertical scales longer than a meter and horizontal scales exceeding a kilometer. We have developed an acoustic instrument which measures the relative velocity between a ship and the water. This instrument operates by measuring the Doppler shift in acoustic energy which is reflected back to the ship by drifting plankton. By time gating the echo, we can determine the relative velocity as a function of depth. By adding the velocity of the ship over the earth to the relative velocity, we can produce a vertical profile of currents measured relative to the earth.

We are identifying those factors which limit the accuracy and spatial resolution of measurements obtained with this system. High frequency motions of the ship caused by waves introduce noise in the current measurements; these motions are easily compensated by making inertial observations of the ship motions. At present, the horizontal resolution is limited by noise in the navigational systems used to obtain the ground speed of the ship. When GPS (Global Positioning System) becomes operational, the performance will be limited by the Doppler determination method used in the acoustic signal processing.

The research consists of theoretical and field studies. The instrument has been used under a wide range of oceanic conditions. Ship ground velocity has been determined from TRANSIT and GPS satellite fixes and from LORAN-C. Most observations have supported by inertial observations of ship motions.

An error model has been formulated based on our experiences. A paper describing the model and the ultimate limitations of the method is in preparation. We continue to study improved processing of the acoustic signal and the navigation data in order to increase the scientific utility of the data. An early version of the system was used in the POLYMODE experiment; results have been recently published.

# REMOTE SENSING OF FLOE SIZE DISTRIBUTION AND SURFACE TOPOGRAPHY

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Remote sensing offers promise for studying sea ice conditions and the processes which change them. At present, there is too little common ground between remotely observable data and the quantities described in sea ice models. Our interest is in identifying measurements which can be made from satellites and which describe properties relevant to the balances of mass, heat and momentum of the ice cover. As a prerequisite, we wish to describe the random spatial structure of sea ice and its field of motion, so that adequate sampling strategies can be devised. Our earlier work has focused on stochastic models of the ice velocity field and of ice thickness.

The present research concerns the piece-like structure of the ice pack, as described by the distribution of floe sizes. (Another useful approach is through lead patterns.) Objectives are 1) to clarify how the many possible definitions of floe size distribution are interrelated, 2) to make measurements of typical distributions 3) to consider the practicality of different measurement techniques, and 4) to investigate the effect of sample size on the measurement error.

Both theoretical and observational work have been involved. The sampling theory gives the variance of an estimate for the fraction g of a test area with diameter D covered by floes of diameter d as $g(1-g)\ N^{-1}$, where $N \cong (D/d)^2$ can be thought of as the number of independent samples in the test area. This relationship and similar ones for other test regions have been confirmed by measurements of sea ice images: LANDSAT visual images, U-2 aerial photographs, and a mosaic of NASA aerial photographs (Hall, 1978, AIDJEX Bulletin 39, Figure 3, summer ice). Several measurement techniques have been tried: 1) measuring inscribed circle diameter by a set of plastic discs, 2) digitizing floe perimeters, and 3) measuring chords (the intersection of a test line with floes).

The basic procedures and theoretical facts are in hand for measuring floe size distribution. Different distributions can be defined and interrelated. We can measure one property and deduce others. Distributions have been measured for several stages of break-up--all of which show distinct floes. The extension to winter conditions where floes are not well defined is being pursued. A useful step now would be to apply these techniques to many images of sea ice, attempting to find patterns in the regional and seasonal variability of floe size distribution.

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# SAR SENSING OF OCEAN SURFACE ROUGHNESS

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Long Term Interests: To study the interaction of Synthetic Aperture Radar (SAR) signals with ocean surface waves and currents in order to extract the physical characteristics of these phenomena.

Objective: To continue the development of an ocean imaging model for SAR which is relevant for actual ocean wave parameters and is applicable to both satellite and aircraft systems.

Approach: To attempt to derive, based on radio scattering theory, a two-dimensional analytical expression for image intensity modulation due to the long ocean waves. This expression should include the modulation transfer function and the modulation due to the motion of the ocean waves. The expression should also be given in terms of azimuth angle (flight direction relative to long wave direction) and the anisotropy of the long waves. The validity of a model based on the expression could then be evaluated for a range of ocean waves and radar parameters. This evaluation will require special processing of SAR data by ERIM.

Status: A generalized two-dimensional analytical exression has been formulated for the image modulation in terms of ocean wave tilt and motion. However, hydrodynamic interaction effects have not been included. The motion expression is usually non-linear for typical radar/ocean parameters, implying that the motion dependence is usually valid only for ocean wave swell. Furthermore, an analytical expression for tilt modulation has been developed in terms of the electrical and physical properties of the ocean waves, however, the expression requires that the waves are travelling at an angle nearly perpendicular to the flight direction.

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## CALCULATION OF OCEAN TIDES

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Long Term Objectives: 1) To develop and test an interpolation technique which allows accurate extrapolation of tidal height fields in ocean basins by making use of selected satellite altimetry measurements and/or conventional tide gauge measurements. 2) To develop a dynamical model of the ocean tides.

Specific Objectives: To test the technique, initially for the M2 tide in a small water body such as Lake Superior, by computing the tide and comparing the results with available tidal data. This will allow us to ascertain the capabilities of the technique for further application in the ocean basins.

Approach: The theoretical foundation is Proudman's theory, reformulated by Dr. Rao. The theory provides the formalism for calculating the gravitational (first class) normal modes and the rotational (second class or Rossby waves) normal modes of irregularly shaped basins with realistic bathymetry. It also allows theoretical calculation of the forced solution to the Laplace tidal equations. The surface height field is only dependent on the velocity potential orthogonal functions. These functions form an optimal set to extrapolate the real tide data over the entire basin through a linear superposition. The coefficients of expansion can be estimated in a least-square sense from available tidal measurements.

Current Status: The technique has been tested by generating the M2 tide in Lake Superior. The dynamical solution was found to agree very closely with available tidal data. The interpolation technique gave excellent results. A report is completed and will be submitted for publication. The method is now being applied to the combined Atlantic and Indian Oceans.

# UPPER OCEAN DYNAMICS AND THERMODYNAMICS

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The investigator's long term interest is to understand the role of dynamical and thermodynamical processes in establishing the surface and near surface thermal and momentum structure of the oceans, their variations, and their relationships to forcing functions and observable surface response.

This specific research task has centered on the variations of the tropical oceans, particularly the sudden anomalous warming in the Pacific known as El Nino and the seasonal equatorial Atlantic behavior. In the tropics, the wind-driven currents cause strong upwelling and advection of thermal signals in the surface layers. Variations in the wind stress lead to changes in surface height, upper ocean content and sea surface temperature (SST), as do changes in the surface heat flux. It is the aim of these studies to understand the relative roles of the thermal and wind perturbations in the atmosphere in inducing long term, climatically important changes in the upper ocean.

The approach taken in this investigation involves theoretical and numerical studies. A two-layer model for the ocean has been constructed which resolves the ocean's mixed layer and thermocline, with non-linear primitive equation dynamics. Coupling of this model with simple atmospheric models is undertaken to examine the wind and heat driven response.

A number of results have been obtained, which shed light on how the dynamic response of the upper ocean is related to the SST response. The changes in SST that can be caused by wind perturbations have been found to be insensitive to the initial thermal fields in a highly non-linear way. This requires that predictions of the wind-driven changes in SST be made with models that resolve thermodynamics, rather than with models that treat but a single reduced gravity layer. The atmosphere must be modelled thermally as well as through a specified haet flux. The research has identified small changes in the southeast trades as being potentially important for El Nino, as much as strong zonal wind anomalies in the western Pacific associated with the Kelvin wave theories. A series of six papers has been prepared on these problems.

# STUDIES IN SUPPORT OF REMOTE SENSING FOR OCEAN CIRCULATION

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Long term interests are the development of techniques for the assimilation and dynamical analysis of remote measurements of ocean circulation parameters.

Specific objectives include the application of estimation theory and ocean dynamics to provide guidance for the design of remote sensing programs, optimization of analysis procedures for existing data sets and to explore combined dynamic analysis of multi-sensor inferences. Methods for data assimilation in numerical models of the ocean are being investigated.

The program is being carried out through the application of the Kalman filter to simplified oceanographic problems, the development of alternative schemes for large scale circulation models, and the investigation of hypothetical measurement programs on stochastic models for the ocean. Ocean general circulation models are being used to study the covariance properties of the flow fields and to evaluate the effect of uncertainty in these properties on the determination of the state of the circulation.

The project is one year old, in which time we have demonstrated the Kalman filter as applied to the equatorial Rossby wave problem, applied estimation theory to the determination of surface currents in a stochastically driven ocean, and developed a sub-optimal filter for incorporating surface height data into vorticity-streamfunction models for the ocean circulation. Work underway includes the refinement and extension of the aplication of estimation theory to the stochastic model, optimization of the vorticity model data assimilation, and development of suitable GCM runs for analysis and testing of estimation methods.

# ANALYSIS OF A SEASAT-IMAGED EVOLVING OCEAN WAVE FIELD

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Objective: To study the small-scale spatial variation of dominant wavelength and direction of an evolving gravity field in the offshore regions of Cape Hatteras, N.C., as imaged by the Seasat SAR. The SAR-derived spectral estimates are then being compared to oceanographic wave/current and wave/topographic interaction theory.

Approach: During previous ERIM studies of this Seasat-SAR data set, the large-scale variations in the dominant wavelength and direction of the surface gravity wave field imaged by the Seasat SAR on 3 September 1978 were documented using optical Fourier transforms of optically processed imagery. The sources of variation in the wave field were identified as the source of gravity waves (Hurricane Ella), a wave/current interaction with the Gulf Stream, and refraction of the gravity wave field as it entered shallow, coastal waters. The approach utilized this year will be to examine the small-scale variation of the gravity wave spectral estimates using fast Fourier transforms of digitally processed Seasat SAR data and then identify the oceanographic cause of the variations. Included as part of this year's analysis will be the determination of the precision and accuracy of the SAR-derived spectral estimates.

Status: Digitally processed Seasat SAR imagery from Revolution 974 has been obtained from the Jet Propulsion Laboratory. Further refinements of the ERIM fast Fourier transform spectral analysis package have been completed. These refinements account for the system transfer function of the Seasat SAR sensor and the motion of scatterers within th SAR-imaged scene. A coastal area has been selected for the wave refraction analysis. In the near future, FFTs of 30 shallow water and 50 deep water regions will be obtained to further analyze the small-scale variations of the surface gravity wave field as detected by the Seasat SAR.

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## ADVANCED SAR SYSTEMS FOR OCEANOGRAPHIC REMOTE SENSING

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Objective: The objective of this task is to explore the feasibility of applying advanced SAR system concepts such as angle diversity, frequency diversity, and multiple antenna systems to oceanographic remote sensing problems.

Approach: This study is being approached from a theoretical as well as an empirical standpoint. A comprehensive theoretical understanding of the principles of operation of the proposed systems is being developed and utilized to predict the performance of these systems. Whenever possible, existing data from prototype sensors or from conventional SAR systems which can be processed to simulate the operation of the proposed sensors is also being employed in this analysis.

Status: Preliminary theorectical analyses of the effects of scatterer motions on angle diversity or spotlight SAR data have been carried out. These analyses are being used to evaluate the image degradation for ocean surfaces on the one hand, and the possibility of extracting ocean current information on the other hand.

An analysis of the feasibility of applying frequency diversity processing methods to SAR data has also begun, and an experiment involving existing large bandwidth aircraft SAR data will be performed.

Finally, advanced techniques for measuring ocean currents are being investigated theoretically and experimentally. An experiment to simulate the results of a multiple-antenna SAR system, again using existing data, has been devised and will be performed in the near future. Results of this experiment will be extrapolated to estimate the performance of a more optimally designed system and to evaluate the feasibility of an advanced SAR system for measuring ocean currents from space.

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# ADVANCED SAR SYSTEMS FOR OCEANOGRAPHIC REMOTE SENSING

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# EXTRACTION OF GRAVITY WAVE SPECTRAL INFORMATION FROM SYNTHETIC APERTURE RADAR

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Objective: To investigate recently proposed methods for extracting the spectrum (i.e., gravity wave information) of the detected image from raw SAR signal data. In particular, the Hasselmann SIFT algorithm and a similar formulation have been examined.

Approach: The proposed image spectrum extraction algorithms have been reviewed and a formulation of the image spectrum in terms of the raw SAR data has been derived. Implementations of the above formulations, in particular, the SIFT algorithm and Martin's approach, have been compared to conventional SAR image formation from the point of view of practical implementation and efficiency. The approximations inherent in each technique have been identified.

Status: The analysis has indicated the above methods appear to bypass the image formation process, when specific processor architectures are analyzed. However, the most efficient forms inherently contain an image formation step. In fact, the preferred implementations are simply conventional SAR image formation processors followed by a two-dimensional Fourier transformation. The results of this study are now in preparation to be published in the IEEE Journal of Oceanic Engineering.

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# LARGE SCALE MODELLING FOR THE APPLICATION OF SATELLITE OCEAN DATA TO AIR-SEA INTERACTION

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Long Term Interests: To investigate the dynamical mechanisms of air-sea interaction, particularly in the tropics, and to predict these interactions.

Specific Task Objectives: 1) To produce monthly data sets suitable for analyzing the variability of the ocean-air interface over the last 130 years. These data sets will be used in forcing ocean models and as ground truth for analyzing satellite data. 2) To theoretically investigate the dynamics of warm western boundary currents. 3) To study the interrelationships between the tropical ocean and atmosphere. 4) To test an interactive model of the global oceanic and atmospheric circulations.

Current Status: A climatological surface condition climatology has been completed for the global ocean at $1^o$ resolution. Sea surface temperature, air temperature near the surface, surface wind stress, and $u^3$ and their variances have been evaluated. An atlas of the results is in preparation. Several anomaly studies involving the tropics and relationships to mid-latitudes are underway.

Model studies of the importance of mesoscale eddies in the time-averaged ocean circulation have been carried out. A conventional model and also an iterative procedure which allows determination of stationary solutions to the model equations were used in the studies. For the first time, it is possible to determine explicitly how transient eddies change the circulation.

A new version of the mixed-layer global ocean model has been tested. In one set of experiments, wind stresses and heat fluxes prescribed from a GLAS Climate Model simulation were used to frce the global ocean; no feedback was allowed. After 90 days, the globally averaged departure from sea surface temperature climatology was $\pm 4^o$ C. In the second set of experiments, the mixed-layer model was forced using wind stresses and heat fluxes derived from monthly climatological values. After two simulated years, the global average monthly departure from sea surface climatology was $\pm 3^o$ C.

Simulations with the GLAS Climate Model have shown that when the model is forced with realistic El Nino-like sea surface temperature anomalies in the equatorial Pacific, the model's dynamic response is remarkably similar to the pattern described by Horel and Wallace. Furthermore, its precipitation response is also very similar to that observed. Enhanced precipitation occurs as a result of an increase in moisture convergence rather than in evaporation.

# PHOTOECOLOGY, OPTICAL PROPERTIES AND REMOTE SENSING OF THE CALIFORNIA BIGHT AND GULF STREAM WARM CORE RINGS

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Objective: The overall objectives of this project are to develop and utilize multi-platform (ship, aircraft, and satellite) sampling strategies and techniques for the purpose of investigating and predictively modeling mesoscale biological processes in the ocean.

Specific Objectives: Specific objectives include a quantitative assessment of the spatial and temporal variability (patchiness) of chlorophyll in the Southern California Bight (SCB) and within Gulf Stream Warm Core Rings (WCR) and their environs. Contemporaneous ship and remotely sensed data are being used in these areas to investigate: the physical and biological processes leading to chlorophyll variability; the ecological and evolutionary significance of this variability; and the relationship of this variability to the distributions of organisms at higher trophic levels. Objectives also include the quantitative modeling of: the radiant energy balance and photoecology of the SCB and WCR; the optical properties of the ocean, as a consequence and function of physical and biological processes; and the appropriate algorithms for the quantitative comparison of ship and remotely sensed data.

Approach: Our general approach is to quantitatively describe the marine photoenvironment and the corresponding bio-optical ocean properties in order to optimize the accuracy of combined ship, aircraft, and satellite data. This includes: the development of state-of-the-art shipboard oceanographic equipments and the continuing optimization of data handling procedures for merging of contemporaneous data taken at sea and from the various aircraft and satellite remote sensors; the development of models with which to link chlorophyll concentrations and the subsequent optical properties (Baker and Smith, 1982).

Status: In the Southern California Bight we have developed techniques for assessing regional phytoplankton biomass and primary productivity (Smith and Baker, 1982; Smith, Eppley and Baker, 1982), and are working toward the assessment of these on a seasonal basis.

In the Warm Core Rings program we have spent nearly 90 days at sea during the past year. Our sea-going equipments operated without significant problems and we obtained the necessary data for support of our own research plus providing collaborative support to NASA's Airborne Oceanographic Lidar (F.E. Hoge) and microwave remote sensing of the ocean (B. Kendall) programs.

# ADVANCED OCEAN SENSOR DEVELOPMENT

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Long Term Interests: To further develop satellite altimetry and related instrument techniques in order to support future missions and oceanic processor program objectives. To advance the key technology required and to develop a physically unambiguous basis for interpretation and quantitative utilization of these microwave observations.

Specific Objectives: (1) Continue to design and begin testing of an end-to-end altimeter simulation system. (2) Begin development of a new radar altimeter system exercisor for laboratory testing.
(3) Begin defining an ocean microwave package for the Shuttle.
(4) Design and test new AGC (automatic gain control) and tracking loop schemes for future altimeters. (5) Simulate new AGC and tracker designs for increased accuracy. (6) Update long range plans.

Approach: We will use GEOS-3 and Seasat altimeter data along with Geosat and TOPEX design information and error budgets as a basis for developing new AGC and tracking systems concepts. These new concepts will be tested against known target areas to optimize the parameters. The appropriate level of theoretical study, laboratory testing, simulation and/or aircraft testing will be performed as necessary. Modest efforts for shuttle microwave package definition will be directed mainly toward the Jackson spectrometer. Software developments and simulations will be investigated by David Hancock (WFF); further AGC studies will be performed by Ray Stanley (WFF). Craig Purdy (WFF) will be involved in all of the hardware developments. Fred Jackson, Travis Walton, and Bert Johnson (GSFC) will be involved in the shuttle package definition.

Current Status: A ten year plan was developed and became available April 1982. Work has begun to update the plan during FY 1983. Results relating to the altimeter AGC design were documented in September 1981, in May 1982, and in April 1982. AGC investigations are continuing to use primarily GEOS and Seasat anomalous response data. Documentation has been developed and initial flow tests were performed on the altimeter simulation system. Further flow tests, optimization of AGC and tracker design, and algorithm development are planned. Technology studies on low power transmitters and rain detection were performed. Tests on low noise pre-amp, fast Fourier transforms, and wide band chirp were completed. Wave tank hardware development produced instrumentation at 9.8 GHz (Doppler), 13.9 GHz, and 35 GHz. Further work at these frequencies and at 5 GHz is planned. A Shuttle mission conceptual design has been presented, and further definition is planned.

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# RADAR STUDIES OF THE SEA SURFACE

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Long-Term Objectives: Radio signals scattered from the sea surface carry information about processes operating at the surface and about undersea phenomena which influence the surface. My long-term objective is to use scattered radio signals to study surface waves, current shear at the surface, geostrophic currents, and oceanic rainfall.

Specific Objectives (Satellite Oceanography): The usefulness of satellite data depends to a great extent on the degree with which the user community understands satellite measuring techniques, their accuracies, and their applicability. To contribute to this understanding, I am completing a book on the Methods of Satellite Oceanography. I am also investigating the accuracy of scatterometer observations of the sea through analyzing the data from the Seasat SASS. In particular, I wish to determine the influence of regional variations in sea surface temperature and oceanic productivity on the accuracy of the observations of wind speed. Temperature influences viscosity, productivity influences surface films, and both then influence the small waves from which radar signals are scattered.

(Oceanic Rainfall): The development of techniques for remotely measuring oceanic rainfall is hampered by a lack of accurate means for calibration. Rain gauges on ships are notoriously inaccurate, and shipborne radars are expensive and not sufficiently developed to yield accurate measurements. Noise produced by rain falling on the sea may offer a new method for calibrating rain rate. A graduate student working with me at the Scripps Institution of Oceanography, J. Nystuen, has begun to measure rain noise in a laboratory tank, in a lake, and in the ocean. He finds a useful correlation between noise and rain rate, and has begun to test proposed methods for separating rain noise from wind noise.

(Geostrophic Currents): I am at present the development flight project scientist for TOPEX, a proposed new alltimetric satellite for measuring surface geostrophic currents (See Yamarone: TOPEX).

# MICROWAVE REMOTE SENSING MEASUREMENTS OF OCEANS AND ICE

Principal Investigator:

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The long term interest of this research is to develop algorithms to quantify geophysical parameters relating to oceanic and ice processes using active and passive microwave sensors. One example of specific objectives in the oceans area is the development of an algorithm to measure wind speed and rain rates in hurricanes using an airborne C-Band Stepped Frequency Microwave Radiometer (SFMR). These measurements are achieved by recognizing that the brightness temperature of rain depends upon electromagnetic wavelength, whereas the surface wind speed does not. An example of algorithm development in the sea ice area is the initial success of a two-frequency radiometric technique of retrieving fractions of multi-year ice, first-year ice, and water. These retrievals have a 90% correlation with surface observations. The approach has been to collect data from aircraft and satellites, in connection with quality surface truth and photography. The electromagnetic signatures of a particular geophysical phenomenon is then characterized as an input parameter for a retrieval algorithm.

For the first time, data collected over sea ice from the Seasat SAR, SASS, and SMMR were simultaneously analyzed. The analysis of aircraft scatterometer/radiometer data collected over Greenland and thin ice is 90% complete, and work on the active/passive analysis of Beaufort Sea ice is well underway. The analysis of radiometric methods of accurately measuring open ocean salinity has been completed. The zeroth order algorithm for analysis of Hurricane Allen data has been upgraded, and the data has been reprocessed to filter out noise. Work has proceeded in an orderly manner in reducing data collected during the Storm Response Experiment (STREX).

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# SATELLITE ALTIMETRY IN THE GULF OF MEXICO

Principal Investigator:

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(joint project with Dr. George Born, JPL
Dr. George Maul, AOML)

Long-Term Interests: To understand the dynamics of the Gulf of Mexico, particularly the Loop Current, large anticyclonic rings shed from the Loop Current, and the circulation in the western Gulf. (2) To understand how large amplitude bottom topography influences intense ocean currents. The influence of the New England Seamount Chain on the Gulf Stream is of special concern. (3) To find optimum techniques for utilizing satellite remote sensors in understanding ocean dynamics. Satellite altimetry is particularly important since it is an all-weather, synoptic instrument providing depth-integrated oceanic information.

Objectives: (1) Use existing altimetric data (GEOS-3 and SEASAT) in conjunction with ground-truth data and results from a numerical model to describe and understand the circulation in the Gulf of Mexico. (2) Develop methods for directly using altimetry data to initialize and update numerical ocean models for studying ocean dynamics and ocean forecasting. Use the Gulf of Mexico model as a test bed for those techniques.

Approach: (1) Use model-generated "synthetic" sea-surface height data with collinear-track SEASAT altimetric data and ground-truth information to describe the circulation in the Gulf of Mexico during SEASAT. (2) Use "perfect" sea-height data from the dynamic ocean model to investigate the problem of using along-track altimetric data to produce near-synoptic objectively-analyzed fields. Contaminate the "perfect" data with likely errors from the geoid, orbit determination, and other sources to study the problem of initializing and updating the dynamic ocean model with noisy altimeter data.

Progress: (1) A paper entitled "Collinear-Track Altimetry in the Gulf of Mexico from SEASAT: Measurements, Models, and Surface-Truth" by Thompson, Born and Maul has been accepted for publication by the Journal of Geophysical Research. (2) Sea heights from the dynamic model have been used to generate synthetic along-track altimeter data. This data has been objectively analyzed and compared with the true height field. Minimum track spacing requirements for detection of the Loop Current and large anticyclonic rings have been determined. (3) A simple one-mode reduced gravity model has been initialized solely by sea surface height information from perfect altimeter with Topex-like orbit. True height fields were generated by the dynamic model. Model forecasts were made using the objectively analyzed altimeter data as the initial field. (4) Work was begun on a new high resolution surface wind field for the Gulf using data from NMC Limited-Fine-Mesh atmospheric prediction model.

# NASA SCIENCE WORKING GROUP ON THE DMSP
# SPECIAL SENSOR MICROWAVE IMAGER (SSMI)

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## 1. Task

The Science Working Group (SWG) was established to assist NASA in answering the following question:

> Based on past experience and findings, what problems of sea ice research are most amenable to solution with the help of passive microwave emission data obtained from a near-polar satellite?

The question is being raised because the new DMSP (Defense Meteorological Satellite Program) to be launched in 1984 will carry a multi-frequency passive microwave imager, called SSMI. Unlike earlier Groups, the present SWG will evaluate the research potential of a given instrument that will be flown in an operational mode until 1991. The SWG will concentrate on issues of basic scientific research and will consider operational applications of the SSMI data only to the extent that such data are of obvious use to resource development and transportation.

## 2. Scientific Background

Virtually all important sea ice problems can be subsumed into one of the two following basic questions:

- What are the source, sink, and transport terms, and their annual cycles in the overall sea ice balance of Arctic and Antarctic waters?
- What is the nature and role of weather systems, and their corresponding ocean counterparts, in the marginal ice zone?

It is generally accepted that the main obstacle to obtaining satisfactory answers to these questions is not a lack of concepts and methods of mathematical simulation but a lack of data. Some of the needed observations can, or may, be acquired by passive microwave remote sensing from space.

## 3. Specific Questions to be Answered

- What type of monitoring data should be acquired with the SSMI that are not now being acquired by other operational sensors, and what specific purpose will such monitoring serve?
- What scientific research can and should be undertaken with the help of SSMI data?
- What research should be undertaken in order to improve the conversion of SSMI images to fields of useful physical sea ice and sea surface parameters?
- How should SSMI data be made available to civilian researchers?

## 4. Status

A contract to cover operational costs of the SWG has been established between NASA and the University of Washington, effective November 1982. A preliminary report to NASA is due by April 1983, and a final report by summer of 1983. The first meeting of the Science Working Group was held at Seattle on 14 and 15 December 1982.

# APPLICATION OF SURFACE CONTOUR RADAR TO OCEANOGRAPHIC STUDIES

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Long Term Interests: To use perfectively registered maps of topography and radar backscatter derived from the Surface Contour Radar (SCR) to: (1) measure oceanographic parameters directly, and (2) evaluate the ability of satellite systems to measure these parameters remotely.

Specific Objectives: (1) To acquire addiional comparative data sets with the wave spectrometer during the fetch-limited wave conditions of the MASEX experiment. (2) To analyze the characteristics of the fetch-limited wave spectrum in detail. (3) To analyze the signal fluctuation statistics in detail and determine the extent to which elevation measurement noise corrupts the spectral measurements. (3) To analyze the backscattering characteristics as a function of angle of incidence, local slope, deviation from mean sea level, and azimuth angle relative to the local wind.

Approach: SCR data will be compared with in-situ sensors, other remote sensors, and the results of simulations and models.

Progress: Three papers aimed at gaining acceptance of the SCR measurements in the oceanographic community were published in 1982, and a fourth is in press. There have been three fetch-limited flights off the eastern seaboard for wind speeds of 10, 15, and 20 m/s. The flightlines were displaced by various distances both north and south of the Delaware Bay. Analysis showed that the wave energy grew linearly with fetch until reaching either the fetch or duration limit. However, in addition to the waves aligned with wind direction which grew with increasing fetch, there were other off shore wave components whose directions differed significantly from the wind direction. These components originated at the mouth of the Delaware Bay. Additional SCR data have been acquired for the study of EM bias, and a paper has been submitted for publication along with companion papers from the Naval Research Laboratory and the Airborne Oceanographic Lidar. Additional SCR data have been acquired with the aircraft in a $13^{\circ}$ bank to obtain incidence angles from 0 to $26^{\circ}$ off-nadir. Preliminary software has determined the mean backscattered power as a function of local slope for six off-nadir incidence angle intervals. Software has been implemented at WFF to routinely determine Doppler corrected, absolutely scaled directional wave spectra and the associated Fourier coefficients. Fred Jackson's wave spectrometer has been installed on the Wallops aircraft and comparative data sets were acquired in the vicinity of Hurricane Debbie on September 17, 1982.

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# STUDIES RELATED TO THE REMOTE SENSING OF SEA ICE

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My principal interest is in the geophysics of sea ice; specifically how the structure of the ice forms and changes with time, and how these changes affect the bulk properties of the ice, particularly its remote sensing signature. I have been specially interested in the potential of SAR in sea ice studies as this remote sensing technique has the capability of providing high-resolution, all-weather imagery that is also of a very high quality in a cartographic sense.

As the earliest possible direct NASA participation in the launch of a SAR bearing satellite would be as part of the FIREX/RADARSAT program, I participated in preparing the sea ice mission requirements for this proposed program (Carsey et al., 1982). I also served as a member of the science working group in a study (Weller et al., in press) investigating the advantages of establishing a SAR receiving station in Alaska. The establishment of such a station is not only essential to obtaining SAR coverage of important arctic areas of interest to US investigators during the FIREX/RADARSAT mission, it would also permit NASA to negotiate to receive data from the SAR systems that will be deployed on the European Space Agency ERS-1 and on the National Space development Agency of Japan radar satellite.

I am also currently preparing the cryospheric portion of the Committee on Earth Science (CES) of the Space Science Board's report entitled "A Strategy for Earth Science from Space in the 1980s" and have recently also published a general interest article on the remote sensing of sea ice (Weeks, 1981). In addition to the technical planning aspects of the first document, both of these reports give compact reviews of the status of the remote sensing of sea ice (the CES document also discusses the seasonal snow cover and large ice caps and ice shelves).

During the last year my primary technical effort relating to remote sensing was the completion of a monograph discussing the growth, structure, and properties of sea ice (Weeks and Ackley, 1982). This work describes in some detail the current state of knowledge of the observed variations in the structural characteristics (grain size, crystal orientation, brine layer spacing) and composition (brine, gas, and solid salts) of sea ice and how changes in these characteristics affect the mechanical, thermal and electrical properties of the ice. In discussing the electrical properties of sea ice, attention is focused on the frequency range 0.1 to 40 GHz as this range is of particular importance to remote sensing. I also co-authored (Cox and Weeks, 1982) a paper that develops a new simple way to calculate the brine and gas content of natural sea ice. This procedure should prove to be quite useful in future ground truth studies for the validation of remote sensing information on sea ice.

## MICROWAVE REMOTE SENSING OF OCEAN WINDS

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Long Term Interest: My long term interest is to assist in the design and development of advanced microwave remote sensors. Also, by studying the satellite data, I hope to better understand the physical processes that govern microwave backscattering and emission from the earth.

Objective: 1) To evaluate and improve the algorithms for retrieving winds from the Seasat SASS and SMMR. 2) To compare the wind sensing performance of SASS versus SMMR. 3) To determine the relationship between the SMMR-observed sun glitter $T_B$, the wind speed, and the sea-surface slope probability distribution.

Approach: The investigation is accomplished in three steps. First, the three months of SASS data are reprocessed by an improved sensor algorithm to obtain more accurate $\sigma°$ values, and the SASS $\sigma°$ Lookup Table is adjusted to be consistent with the observed statistical variations of the $\sigma°$'s. The updated Lookup Table is then used to compute wind vectors from the $\sigma°$'s. Step 2 involves processing the SMMR $T_B$'s through a least-squares geophysical algorithm. The resulting SMMR winds are expected to be more accurate than those currently available. In the final step, the SASS and SMMR winds are compared on an orbit-by-orbit basis over the three months, and the SMMR-observed sun glitter $T_B$ is correlated with the SASS winds.

Status: In FY82 the entire SASS data set was reprocessed by an improved sensor algorithm, and the newly generated $\sigma°$'s were stored on 16 magnetic tapes. Copies of these tapes were made available to other investigators. The dependence of $\sigma°$ on incidence angle and polarization was compared to that given by the current Lookup Table and by geometric optics. The comparisons show that, in general, the Lookup Table accurately models $\sigma°$ on a global basis, with there being no obvious regional or temporal differences. However, there were some small inconsistencies that indicated the Lookup Table should be slightly modified.

This investigation is jointly sponsored NASA and the Atmospheric Environment Service, Toronto, Canada.

# SMMR ALGORITHM REFINEMENT TASK

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Long-term Interests: The precise measurement of sea surface temperature and wind speed at the ocean's surface are critical elements in understanding the global energy and momentum balances which, in turn, determine the Earth's climate.

Specific Objective: The purpose of this task is to refine the algorithms used for retrieving the temperature and wind speed at the ocean surface, to improve their accuracy, to understand their limitations, and, where possible, to reduce those limitations.

Approach: Algorithm refinements have, in previous years, been made based on pre-launch geophysical and instrument calibration models. The sea surface temperature retrieval performance based on these models was quite encouraging based on a few months of data. However, serious discrepancies in the wind speed retrievals indicated problems with the model which described the change in the sea surface emissivity induced by surface wind. This modelling problem could also introduce quasi-random uncertainties in the sea surface temperature retrievals. Also, systematic errors in the SST retrievals with large spatial and temporal scales suggested a residual instrument calibration error component. In order to reduce these error sources, the algorithms were tuned cautiously. Multiple linear regression techniques were used to generate corrections based on the 10.7 and 18 GHz brightness temperatures (both polarizations), the angle at which the SMMR views the Earth's surface, and three temperature readings within the instrument. The regression was based on minimizing the RMS difference between the SMMR derived SST and climatology over 9 months of data (December 1978 - August 1979). Data with known problems (e.g. within 600 km of land) were deleted.

Current Status: This tuning reduced the apparent error in the SMMR retrievals by about 10%. The brightness temperature terms contributed slightly more than half this improvement, suggesting that the sea surface modelling error was somewhat more serious than variable calibration errors. This tuned algorithm is being used in the Nimbus Experiment Team first year data set production.

# SEASAT SCATTEROMETER MARINE WIND ANALYSES

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## Long Term Interests

I am interested in developing efficient automated techniques to produce high-resolution global data records of scatterometer wind-stress vectors over the sea surface from raw scatterometer data containing multiple direction solutions for each observation. This includes current (Seasat) as well as proposed scatterometer configurations. The wind stress vector is a major fundamental geophysical parameter required for both atmospheric and oceanographic scientific research problems and application projects with economic benefits. NASA's Seasat mission during the summer of 1978 presented the meteorological and oceanographic community an unprecedented density of global wind-stress measurements over the oceans hitherto unavailable except in regional pockets during intensive research. In addition to applying the dealiased scatterometer data to atmospheric and oceanic research problems, I am interested in characterizing the physics of the scatterometer signal in relation to the geophysical parameters of the air-sea interaction processes. The current scatterometer models relating the signal to surface winds are dominantly empirical.

## Objectives of this Research Task

The objectives of this task are to conduct analyses and produce a data record of unique wind-stress vectors from the Seasat scatterometer (SASS) "raw" data record (containing multiple direction solutions for each observation --- called "aliases"), and to perform research utilizing the resultant data. Specifically, these research tasks are:

1) improvement of automated SASS de-aliasing techniques --- including both objective and analyst procedures

2) application and utility of SASS data to forecast studies

3) determination of statistics of storm momentum exchange with the oceans

4) Southern Hemisphere marine meteorological studies

5) characterization and error analyses of the scatterometer signal relating it to winds and other geophysical parameters of the air-sea interaction process

This task includes the generation of an atlas of the dealiased scatterometer wind vectors.

## Approach

To produce the dealiased scatterometer wind data record, analyses will be constructed from charts of SASS data (produced by AES-CANADA) having multiple direction solutions in a manner to be consistent with meteorological principles, with satellite cloud imagery, with ship and buoy reports (plotted on same-scale charts as SASS data), and with sea-level weather charts. Duplicate analyses for each global day of data will be utilized to ensure and estimate the quality of the dealiased SASS data. A digitizer will be used to generate a data record of SASS polygon/quadrant-directions representing in an efficient manner the analyst-dealiased SASS wind vectors. The polygon file thus generated will be merged with the scatterometer data file to create a data record of unique wind vectors. The data produced will then be analyzed for the meteorological and oceanographic studies noted above. This research study is jointly funded by the Atmospheric and Oceanic Processes Branches of NASA. This effort represents a joint study between ourselves, UCLA (M. G. Wurtele), AES-CANADA (S. Peteherych) and NASA-GSFC (R. Atlas). We also have contributions to these research studies by dB Enterprises (D. H. Boggs).

## Current Status:

This task started in FY'82. The analysis techniques and software are nearly complete to efficiently produce a dealiased SASS data record. A nine-day-global-data set of dealiased SASS winds is scheduled to be completed early in 1983. A second eight-day-global set of dealiased SASS winds is scheduled for early spring. A preliminary model function relating the SASS signal to winds has been developed incorporating geophysical parameters sensitive to sea surface temperature. The new SASS model is currently being evaluated.

# DETERMINATION OF THE GENERAL CIRCULATION OF THE OCEAN AND THE MARINE GEOID USING SATELLITE ALTIMETRY

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Objective: The overall objectives of this project are to understand the capabilities of satellite altimetry and related measurements (e.g., scatterometry) for the purpose of determining the general circulation of the ocean and its variability. We are exploring existing data and examining the prospects of future data - both altimetric and conventional - in order to determine optimum experimental schemes and optimum data handling procedures.

Specific Objectives: There are several specific tasks undertaken in the past years: (1) Determination, with the TOPEX Science Working Group, of an optimum set of scientific requirements for a future altimetric satellite mission and its relationship to international general circulation programs. (2) Construction of an optimum gravimetric geoid in the North Atlantic for use with the altimetry. (3) Examination of the long wavelength components of SEASAT altimetry in the Pacific Ocean. (4) Construction of sea surfaces from hydrographic data for future use with altimeter surfaces.

Approach Used: Our general approach to most of these problems is in the general context of inverse theory; i.e., a form of systematic model making.

Status: (1) The P.I. remains in touch with current NASA efforts to fly TOPEX. (2) V. Zlotnicki is completing his thesis work and has constructed an optimum gravimetric geoid for the North Atlantic. The procedure is described in a paper by Zlotnicki, Parsons and Wunsch (1981) and involves using inverse theory to produce an optimum surface. (3) C.-K. Tai and C. Wunsch (1982) have shown that at long wavelengths even the sub-optimum SEASAT data set is capable, when combined with the GEM-9 geoid, of yielding realistic absolute ocean surface topography. Tai (1982) has described the procedures in detail. (4) Our model making of hydrographic circulation continues (jointly supported by NSF). Roemmich and Wunsch (1981) have elaborated on the methods described by Wunsch and Gaposchkin (1980) to show how altimetry and hydrography would be combined together. This work is continuing to understand the extent to which realistic future altimeter missions could constrain climatologically important variables like heat flux. (5) We are awaiting the release of direction corrected SEASAT scatterometer data before attempting any intensive look at the scatterometer winds.

# PHOTOECOLOGY, OPTICAL PROPERTIES, AND REMOTE SENSING OF WARM CORE RINGS

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Long Term Interests: The long term interest of the investigator is to understand how physical and biochemical systems affect the distribution of light-absorbing and light-emitting micro-organisms in oceanic waters.

Objectives of This Research Task: We are attempting to characterize hydrographic regions throughout a Warm Core Ring by using optical signatures. This requires the measurement of fluorescence excitation and emission spectra as well as the diffuse attenuation of spectra of visible light. Specifically, we have concentrated on the high velocity region of the eddy and the region that is warm center.

Approach: We pump water throughout the water column to a depth of 200 m. This water is passed through fluorometers which are fitted with filters for measuring specific excitation and emission fluorescence. In conjunction, we take specific water samples for measuring the spectral characteristics of fluorescence and excitation as well as the spetrophotometric measurement of diffuse attenuation spectra. In addition to the discrete samples, we extract the pigments and count the principal species.

Current Status: At the onset, we hypothesized that a pattern of phytoplankton distribution in time and space in a Warm Core Ring would be the result of variations in the buoyancy of the water masses associated with the eddy. Shipboard and satellite optical observations confirmed this and also showed that the convective overturn is an important mechanism in regulating the distribution of phytoplankton. The central core of the warm core eddy experiences two bursts of phytoplankton growth and they are out of phase with the seasonal changes observed in slope and shelf water at the same latitude.

This work has been jointly supported by NOAA, NASA, and NSF, and the State of Maine.

# MESOSCALE ICE DYNAMICS AND PROCESSES/OBSERVATIONAL

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Long Term Interest: (1) To investigate the frequency and areal extent of polynyas inside the ice pack and study possible mechanisms for their existence. Persistent and temporary openings in the ice pack, especially those near the continental shelves during winter months, will be studied and related to oceanic and atmospheric processes.
(2) To investigate sea ice dynamics and processes near the ice edge and short and long term variability of sea ice extent.

Objectives: (1) To study the characteristics of near and offshore polynyas in the Antarctic region with emphasis on those adjacent to the ice shelves, (2) to quantify the rates of ice growth and decay at various areas in the polar region, and (3) to investigate the ice extent variability in both hemispheres.

Approach: Daily averages of Nimbus-5 ESMR brightness temperature data will be used to investigate short (or long) term openings or closings of near or offshore polynyas. The main emphasis will be to study areas located near the continental ice shelves. Statistical analysis will be applied to separate real openings from spurious ones caused either by data retrieval problems or by atmospheric effects. To study rates of ice growth and decay, the brightness temperatures are plotted as a function of position along the ice edge at some fixed locations. Changes in this distribution with time are then quantified and analyzed.

Status: Five locations near ice shelves around the Antarctic continent have been investigated. About 300 x 300 km areas have been chosen and the parameters analyzed with time include: minimum, maximum, and average brightness temperatures, and standard deviations of brightness temperatures in the area. Analysis of these results is in progress. Also, spatial distributions of brightness temperatures along the ice edges have been generated during some times of the year and are being analyzed.

# MESOSCALE ICE DYNAMICS AND PROCESSES/REMOTE SENSING

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Long-term Interest: To investigate the microwave emissive properties of various types of sea ice, at different frequencies and polarizations as observed from a space platform. Existing techniques will be improved and new methods will be developed to include various effects like age, thickness, snow cover, and wetness, in the extraction of sea ice geophysical parameters.

Objectives: (1) Measure the wavelength and polarization dependence of the microwave emissivities of first-year and multiyear ice, (2) examine the temporal and spatial variabilities of the emissivities of the various ice types, and (3) study how to utilize the multispectral satellite microwave data in identifying effects of thickness, snow cover, roughness, and weather.

Approach: Near simultaneous images of the Scanning Multichannel Microwave Radiometer (SMMR) and the Temperature Humidity Infrared Radiometer (THIR), both onboard the Nimbus 7 satellite, will be used to obtain global measurements of emissivities in consolidated ice regions. Multispectral "cluster analysis" will be used to separate the various ice types and to obtain the corresponding emissivities of each type at the various channels. Time dependent effects like snow cover, weather and ridging will also be studied by examining series of measurements at the same area over a year cycle. Effects of snow wetness and melting will be investigated by comparative analysis with in-situ data, like the extensive ice observations from the October-November, 1981 US/USSR Weddell polynya expedition (WEPOLEX). Infrared and visible channel data will also be utilized to investigate ice characteristics in the neighboring area during the same period, and to study microwave signature of thin ice formed in nearshore polynyas.

Status: A paper on sea ice emissivities in the Arctic has been submitted to the Journal of Geophysical Research. A report containing more details on the results and also results from the Antarctic region is in preparation. Effects of snow cover, wetness, surface melt, and flooding are currently being studied in collaboration with S. Ackley at Cold Regions Research Laboratory (CRREL).

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# SECTION IV - BIBLIOGRAPHY

This section contains a list of scientific research papers supported wholly or in part by NASA which were published or accepted for publication in refereed journals in 1981 and 1982.

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15. Supplementary Notes

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16. Abstract

This, the Third Annual Report for NASA's Oceanic Processes Program, provides an overview of our recent accomplishments, present activities, and future plans. Although the report was prepared for Fiscal Year 1982 (October 1, 1981 to September 30, 1982), its Introduction includes the period extending into March 1983. Sections following the Introduction provide summaries of current flight projects and definition studies, brief descriptions of individual research activities, and bibliography of refereed journal articles appearing within the past two years.

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